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"One's knowledge of science begins when he can measure what he i
speaking about and express it in numbers."—THOMSON.

"We owe all the great advances in knowledge to those who endeavor t
find how much there is of anything."—MAXWELL.

Physical Laboratory Manual and Note Book

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PHYSICAL LABORATORY

MANUAL AND NOTE BOOK,

INCLUDING

MORE THAN TWO HUNDRED EXPERIMENTS AND EXERCISES,
AND ESPECIALLY ADAPTED TO ACCOMPANY THE
AUTHOR'S TEXT-BOOKS ON PHYSICS.

BY

ALFRED P. GAGE, PH.D.,

AUTHOR OF "ELEMENTS OF PHYSICS," "INTRODUCTION TO
PHYSICAL SCIENCE," "PHYSICAL TECHNICS," AND
"ONE THOUSAND EXERCISES IN PHYSICS."

BOSTON, U.S.A.:
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PREFACE.

The preparation of a manual of experimentation in Physics is attended with peculiar difficulties. Yet, to secure to both teacher and pupil the greatest economy of time and labor, a manual has come to be considered as well-nigh indispensable. There are obvious advantages gained by the teacher in using the same manual, and pursuing familiar methods, from year to year.

The following are, in brief, my views with reference to the scope and character of such work in experimental physics as best suits the purposes for which the High School is designed, and it has been my aim to prepare a manual in harmony with these views.

(1) Experiments should be selected which are especially adapted to laboratory practice, and which require thought, close observation, and a moderate length of time in their performance; experiments which are merely illustrative, and whose results may be made perceptible to a large number at the same time, may well be taken up as a class-room exercise.

(2) Both quantitative and qualitative experiments should be given, but the former ought always to involve some important principle or lesson to be derived therefrom.

(3) Experiments which promote chiefly dexterity and acquaintance with methods, and which do not call into intense action the reasoning faculties, cannot be regarded in any high sense as educational, and therefore ought not to be introduced into our high schools. The secondary school must not ape the technological school.

(4) Experiments must be selected with a view to economy of time. Hence, such as depend for their value wholly upon their accuracy, such, especially, as require considerable time for preparation, after the apparatus has been used, and such as are correct in theory but difficult in practice, must be avoided.

(5) Experiments should illustrate or verify principles previously discussed in the class-room. Life is too short to admit of teaching physics inductively to any great extent; of rediscovering laws which have required ages to discover.

(6) Finally, experiments ought to be progressive, so as to be adapted to all degrees of talent, industry, and ambition. The practice of simultaneous exercise, and of "keeping scholars back for the purpose of keeping them together" — the bane of our modern schools — may easily be, and ought to be, discarded in laboratory practice.

With reference to the plan of the manual I would say, that my aim has been to state in plain, "every-day" language just those details, in their order, which the pupil must observe, unencumbered so far as practicable with details concerning the construction of apparatus. This is not a guide-book for the manufacture of apparatus. The cuts given in the manual suffice to enable the pupil to work intelligently with the apparatus before him, also to render his notes intelligible when read in connection with the requirements, without wasting time in making drawings of the apparatus used.

It is not expected that the experiments will be performed in the order in which they occur in this manual, as the order is usually of little consequence. It is better that two experiments which are expected to give the same results should not be performed simultaneously in the same room. Apparatus need be duplicated, even with large classes, only when a multiplicity of experiments is to be performed by each pupil with the same apparatus, such, notably, as balances and weights used in finding specific gravity, and apparatus used in electrical measurements, and other instruments in common use for measuring.

Experiments suited to the pupils' individual capacities should be selected. Few, comparatively, will be able, or will have time, to perform all the work covered by this manual.

Strict observance of the directions given, carefulness and neatness of execution, should be enjoined, and accuracy in results should be insisted upon. Yet these requirements may be carried too far. For example: to ascertain the specific heat of a substance under the most favorable circumstances, guarding against all possible sources of error, would consume many hours of an expert's time. If an inexperienced high school student were to attempt to attain a like degree of accuracy in this and similar work, the number of experiments which he would perform in an ordinary school course would be very limited, and the general knowledge of physical laws which he would acquire would be proportionately small. Evidently, then, the methods adopted and the degree of accuracy insisted upon, must be determined with discretion, else laboratory methods will, very properly, fall into disrepute. The directions given in this manual for finding specific heat are not such as are calculated to yield the most accurate results, but are given with due regard to the facilities which ordinary school laboratories afford, the difficulties arising from having many pupils follow one another in succession, and the pittance of time at command. It is well for the pupil to indicate sources of error, and suggest methods by which they may be eliminated.

HINTS TO TEACHERS.

Pupils should be required to write on the blank pages the entire mathematical computations by which their results are obtained. In case these computations are very long and tedious, the different operations may be appropriately represented by mathematical signs and characters. All concrete numbers should be properly denominated; and quantities, such as velocity, density, etc., which require two quantities to represent them, should be fully expressed.

The graphical method of representation of physical quantities should be practised, as time and the maturity of the pupil will admit. The method of plotting (see directions, p. 1, "Physical Technics") should be adopted, especially when it is desired to discover a law connecting a series of simultaneous measurements of two quantities; *e.g.* the lengths, l, and the times, t, of vibration of a simple pendulum. Inspection of the line drawn through the plotted points obtained by using these quantities respectively as ordinates and abscissas would show that t is not proportional to l, but to some power of l. Plotting paper (say) 5 in. on a side, and ruled in squares of tenths of an inch, with every fifth line heavier, is very suitable. These papers may be pasted on the blank pages after the plotting is completed.

Tabulation of results should be insisted on, whenever a series of measurements are made.

Lead-pencils are most convenient for recording results, but their use should not encourage slovenliness. A cheap ruler with metric divisions, and an eraser, should be kept in a drawer at each desk.

Incomplete portions of the printed pages may be utilized by the pupil, by writing therein additional experiments or directions dictated by the teacher. Tops of the blank pages may be used for the same purpose.

It is recommended, when circumstances will admit, that the experiments be performed individually by the pupils with no communication or collusion between one another, except in cases where the proper manipulation requires more than one person.

The teacher should endeavor to anticipate difficulties which the inexperienced are likely to encounter, and give to his class, collectively, explicit directions how to overcome them, as well as multifarious directions accompanied by illustrations concerning manipulation, all of which can be much better imparted *viva voce* than by tedious text-book descriptions.

The laboratory is a *workshop;* its furnishings should be firm and substantial, with no tendency to lavishness. Heavy-top pine tables, filled with linseed oil, fastened securely to the floor, furnished with gas, without any iron trimmings, having a single drawer for each desk space; a large soapstone sink, with the usual water fixtures and overflow pipe, and cases or lockers for holding apparatus, constitute about all that is needed for a physical laboratory equipment. The tables should be numbered on the edges at intervals of about thirty inches. On a blackboard may be written the numbers of the experiments in the manual, and the numbers of the desks where apparatus, suited to each, may be found. When practicable, provision should be made for more pupils than the class numbers, that no time be lost in waiting for apparatus. Apparatus should not be withdrawn until all, of whom there is any hope, have used it.

RULES FOR THE PHYSICAL LABORATORY,

DICTATED BY THE INSTRUCTOR AND COPIED BY THE PUPIL.

FORMULAS AND TABLES.

FORMULAS FOR CALCULATING AREAS AND VOLUMES.

$\pi = 3.1416.$

Area of triangle (altitude a, base b) $= \frac{ab}{2}.$

" circle (radius R) $= \pi R^2.$

" surface of sphere (diameter D) $= 4\pi R^2 = 4$ great circles.

" " cylinder (hight h) $= 2\pi R\,(R + h).$

Volume of sphere $= \frac{\pi D^3}{6}.$

" cylinder or prism (area of base a, hight h) $= ah.$

" cone or pyramid $= \frac{ah}{3}.$

TABLE OF METRIC AND BRITISH EQUIVALENTS.

Measures of Length.

1 in. = 2.540 cm.
1 ft. = .3048 m.
1 yd. = .9144 m.
1 m. = 1.609 km. = about 1⅗ km.

1 cm. = .3937 in.
1 m. = 1.094 yds. = 39.37 in.
1 km. = .6214 m. (about ⅝ m.).

Measures of Surfaces.

1 sq. in. = 6.45 qcm.
1 sq. ft. = 929.03 qcm.
1 sq. yd. = 25.29 qm.
1 sq. m. = 2.59 qkm.

1 qcm. = .1550 sq. in.
1 qm. = 1.196 sq. yd.
1 qkm. = .3861 sq. m.

Measures of Volume and Capacity.

1 cu. in. = 16.387 cc.
1 cu. ft. = 28.317 qdm.
1 cu. yd. = .764 cbm.

1 cc. = .061 cu. in.
1 cbm. = 1.308 cu. yd.

1 cbdm. = 1 liter = 1000 cc. = 1.057 American (*i.e.* wine measure) quarts (about 1 qt.).
1 American qt. = 32 fluid ounces = .9463 liter.
1 fluid ounce = 29.571 cc.
1 liter = 61.027 cu. in.
1 gall. (wine measure) = 231 cu. in. = 3.785 liters.
1 dry quart = 1.101 liters.
1 liter = .908 dry quart.

Measures of Weight.

1 oz. Av. = 28.35 g.
1 lb. Av. = .4536 kg. (about $\frac{5}{11}$ kg.).
1 oz. Troy = 31.1035 g.
1 lb. Troy = .3732 kg.

1 g. = .03527 oz. Av.
1 kg. = 2.2046 lbs. Av. (ab't 2.2 lbs.).
1 g. = .02215 oz. Troy.
1 kg. = 2.679 lbs. Troy.

1 cu. ft. of water at 62° F. weighs 62.321 lbs. Av., or about 1000 oz. Av.

1 cu. in. of water at 62° F. weighs .036 lb. Av.

Pressure in water increases at the rate of about 62.3 lbs. per sq. ft., or about $\frac{1}{3}$ lb. per sq. in. for each foot of depth; or at the rate of 1 gram per sq. centimeter for each centimeter of depth; or 1 kg. per sq. centimeter for each meter of depth.

Work.

1 erg = 1 dyne-centimeter = .0000001 joule = $\frac{1}{981}$ gram-centimeter.
1 ft. lb. = 13562600 ergs = .13825 kgm. = .0012953 lb.-F.
1 kgm. = 7.23314 ft. lbs.

Heat.

1 gram-centigrade = .001 kilogram-centigrade.
1 lb.-F. = 772 ft. lbs. = 1047.03 joules.

Power.

1 erg per sec. = .0000001 watt or volt-ampere.
1 watt = 44.2394 ft. lbs. per min.
1 horse-power = 745.941 watts = 42.746 lbs.-F. per min.

TABLES OF SPECIFIC GRAVITIES AND DENSITIES.

Solids.

Alum	1.724	Copper, sheet	8.870
Aluminium	2.670	Diamond	3.530
Antimony	6.712	Ebony	1.187
Beeswax	0.964	Galena	7.580
Bismuth	9.822	Glass, crown	2.520
Brass, cast	8.380	" flint	3.000 to 3.500
" sheet	8.400	Gold	19.360
Camphor	0.988	Granite	2.650
Cedar	0.554	Graphite	2.500
Cherry	0.710	Ice	0.920
Coal, Anthracite	1.300 to 1.800	Iron bar,	7.788
" Bituminous	1.260 to 1.400	" cast	7.210
Cork	0.240	" pyrites	5.000
Copper, cast	8.830	Lead, cast	11.360

Solids. (*Continued.*)

Lead, sheet	11.400	Rock-salt	2.257
Limestone	3.180	Sand, fine	1.520
Magnesium	1.750	Silver, cast	10.470
Maple	0.755	Slate	2.880
Marble	2.720	Sodium	0.970
Pine, white	0.554	Sulphur, native	2.033
" yellow	0.461	Tin, cast	7.290
Platinum	22.069	Walnut	0.680
Potassium	0.865	Zinc, cast	7.000
Quartz	2.650		

Liquids.

Alcohol, absolute	0.800	Nitric acid	1.420
" common	0.833	Oil of turpentine	0.870
Bisulphide of carbon	1.293	Olive oil	0.915
Ether	0.723	Sea-water	1.026
Hydrochloric acid	1.240	Sulphuric acid	1.841
Mercury	13.598	Water, 4° C., distilled	1.000
Milk	1.032	" 0° C., "	0.999
Naphtha	0.847		

Gases.

[Standard: air at 0° C.; barometer, 76 cm.]

Air	1.0000	Hydrogen	0.0693
Ammonia	0.5367	Nitrogen	0.9714
Carbonic acid	1.5290	Oxygen	1.1057
Chlorine	3.4400	Sulphureted hydrogen	1.1912
Hydrochloric acid	1.2540	Sulphurous acid	2.2474

TABLE OF RESISTANCE OF WIRE,

Chemically pure, one meter long, one millimeter in diameter, at 0°*C.* (Jenkin). *Also relative resistances* (Ayrton).

			Relative Resistances.
Silver, annealed	.01937	ohm	1.000
" hard drawn	.02103	"	1.086
Copper, "	.02104	"	1.086+
Zinc, pressed	.07244	"	3.741
Platinum	.11660	"	6.022
Iron, annealed	.12510	"	6.460
Lead, pressed	.25270	"	13.050
German silver	.2695	"	13.92

DIMENSIONS OF WIRE GAUGE SIZES,

In decimal parts of an inch.

No. of Wire Gauge.	Size of each No. in decimal parts of an inch of the American Wire Gauge.	Size of each No. in decimal parts of an inch of the Birmingham Wire Gauge.	No. of Wire Gauge.	Size of each No. in decimal parts of an inch of the American Wire Gauge.	Size of each No. in decimal parts of an inch of the Birmingham Wire Gauge.
0000	.460	.454	19	.03589	.042
000	.40964	.425	20	.03196	.035
00	.36480	.380	21	.02846	.032
0	.32486	.340	22	.02535	.028
1	.28930	.300	23	.02257	.025
2	.25763	.284	24	.0201	.022
3	.22942	.259	25	.0179	.020
4	.20431	.238	26	.01594	.018
5	.18194	.220	27	.01419	.016
6	.16202	.203	28	.01264	.014
7	.14428	.180	29	.01126	.013
8	.12849	.165	30	.01002	.012
9	.11443	.148	31	.00893	.010
10	.10189	.134	32	.00795	.009
11	.09074	.120	33	.00708	.008
12	.08081	.109	34	.0063	.007
13	.07196	.095	35	.00561	.005
14	.06408	.083	36	.005	.004
15	.05707	.072	37	.00445	
16	.05082	.065	38	.00396	
17	.04525	.058	39	.00353	
18	.0403	.049	40	.00314	

TABLE OF TRIGONOMETRICAL FUNCTIONS.

Degree.	Tangent.	Sine.	Degree.	Tangent.	Sine.	Degree.	Tangent.	Sine.
1	.017	.017	31	.601	.515	61	1.80	.875
2	.035	.035	32	.625	.530	62	1.88	.883
3	.052	.052	33	.649	.545	63	1.96	.891
4	.070	.070	34	.675	.559	64	2.05	.899
5	.087	.087	35	.700	.574	65	2.14	.906
6	.105	.105	36	.727	.588	66	2.25	.914
7	.123	.122	37	.754	.602	67	2.36	.921
8	.141	.139	38	.781	.616	68	2.48	.927
9	.158	.156	39	.810	.629	69	2.61	.934
10	.176	.174	40	.839	.643	70	2.75	.940
11	.194	.191	41	.869	.656	71	2.90	.946
12	.213	.208	42	.900	.669	72	3.08	.951
13	.231	.225	43	.933	.682	73	3.27	.956
14	.249	.242	44	.966	.695	74	3.49	.961
15	.268	.259	45	1.000	.707	75	3.73	.966
16	.287	.276	46	1.036	.719	76	4.01	.970
17	.306	.292	47	1.07	.731	77	4.33	.974
18	.325	.309	48	1.11	.743	78	4.70	.978
19	.344	.326	49	1.15	.755	79	5.14	.982
20	.364	.342	50	1.19	.766	80	5.67	.985
21	.384	.358	51	1.23	.777	81	6.31	.988
22	.404	.374	52	1.28	.788	82	7.12	.990
23	.424	.390	53	1.33	.799	83	8.14	.993
24	.445	.407	54	1.38	.809	84	9.51	.995
25	.466	.423	55	1.43	.819	85	11.43	.996
26	.488	.438	56	1.48	.829	86	14.30	.998
27	.510	.454	57	1.54	.839	87	19.08	.999
28	.532	.469	58	1.60	.848	88	28.64	.999
29	.554	.485	59	1.66	.857	89	57.29	1.000
30	.577	.500	60	1.73	.866	90	Infinite	1.000

GENERAL EXERCISES.

1.

Take a point, *A*, on the opposite page; draw a line, *AB*, about 1 in. long, and place an arrow-head in it to indicate, in the usual (book) method, a direction vertically up.

2.

From the same point, *A*, draw a line, *AC*, to represent a horizontal direction.

3.

From the same point, *A*, draw a line, *AD*, to represent an oblique downward direction.

4.

Which angle formed by these lines is a right angle?

5.

Is the angle, *DAC*, acute or obtuse?

6.

On a scale of $\frac{1}{4}$ of 1 in. ≎ 1 in., draw a line, *AB*, to represent a distance, in a horizontal direction, of 1 ft. 3 in.; draw also a line, *DC*, to represent a distance in the same direction, of 9 in.

7.

a. Express in the form of a fraction the ratio of the first distance to the second.

b. Express the corresponding inverse or reciprocal ratio.

8.

Ap.: circular piece of tin about the size of a half-dollar having a radial line scratched upon one of its sides; short metric rule.

a. Draw a straight line widthwise the blank page. Place the circular tin edgewise on the line as near to the left extremity of the line as convenient, and so that the end of the radial line shall touch the ruled line and be perpendicular to it. Make a visible point in the ruled line where these two lines meet, and place the letter *a* near this point. From this position roll the tin along the ruled line until the two lines again meet and are at right angles to each other. Locate this point of meeting and letter it *c*. Measure the distance between these two points in millimeters and tenths of a millimeter (dividing with the eye as nearly as practicable). What dimension of the circular tin is this quantity?

b. Measure the diameter of the tin.

c. Divide the first of the two numbers obtained above by the last, carrying the division to four decimal places, and state to what decimal place the quotient corresponds with the value of π given on p. vii.

d. What does π represent?

9.

Ap.: pair of pencil dividers; metric rule.

Draw a circle of $2^{\text{cm.}}$ radius.

10.

Calculate the circumference of the circle drawn above.

11.

Calculate the area of this circle (see formula p. vii).

12.

Calculate the area of a sphere having the same diameter as this circle.

13.

Calculate the volume of this sphere.

14.

Ap.: meter and yard-stick, and block of wood with a plane surface.

a. Measure to the nearest millimeter the length of yo table, expressing the result in meters and a decimal.

Place the plane surface of the block vertically against t end surface of the table, and measure from this surface at o end to the same surface placed at the other end. [If nece sary, a chalked string may be placed lengthwise the table, right angles to the end surfaces, and snapped so as to leave chalk mark on the table, along which to measure.]

b. Compute its length in feet and a decimal (see Table o Equivalents); also express the length in feet and inches.

c. Measure its length in feet and inches, and state wha difference there is in the results as obtained by the tw methods.

15.

a. Measure the width of your table in meters.

b. Make a drawing of the top surface of your table on a scale of $1^{\text{cm}} \Leftrightarrow 25^{\text{cm}}$.

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16.

Ap.: metric rule, two rectangular blocks, balance, metric weights, an iron ball.

a. Measure the diameter of the ball as suggested by Fig. 1

b. Calculate the area of its surface.

c. Calculate its volume.

d. Find its mass.

e. Determine from preceding data the density of iron.

f. What is the density of water?

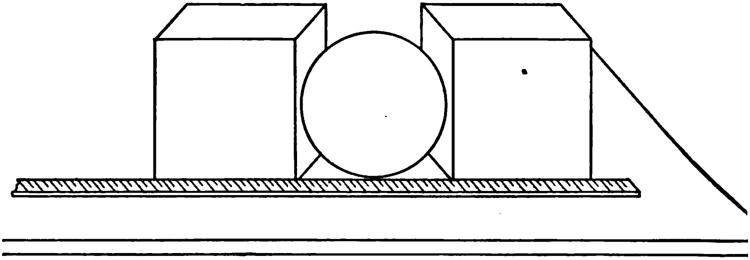

FIG. 1.

g. How many times denser is iron than water?

h. What volume of water would have the same mass as the iron ball?

i. If the iron ball were put into a tumbler brimful of water, what volume of water would run over? What mass of water would run over?

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ig.

17.

Ap.: small solid cylinder (*e.g.* a rod of metal), metric rule, calipers (better micrometer calipers), balance, and weights.

a. Measure the diameter and length of the cylinder. See whether its diameter is uniform. If not, measure its diameters at intervals of (say) 1^{cm} and get the average diameter.

b. Calculate the area of a cross-section, taking for the diameter of the circle the average diameter of the cylinder.

c. Calculate its volume. (Volume of cylinder = area of cross-section × length.)

d. Find its mass.

e. Find its density.

18.

Ap.: metal tube, interior and exterior calipers, and metric rule.

Measure the length of the tube and its interior and exterior diameter, and from these data compute the volume of metal in the tube.

19.

Ap.: balance (Fig. 15), set of weights from 10^{g} to 1^{cg}, metric rule 30^{cm} long; rectangular block of wood 5 to 4^{cm} long, 4 to 3^{cm} wide, 2.5 to 1.5^{cm} thick.

Get volume, mass, and density of block of wood. — Take four measurements of the length of the block, one at each edge (or one at the middle of each side). Average these to get the average length. Get the width and thickness of the block in the same way.

In measuring apply the division mark 1 (^{cm}) to one edge of the block (*i.e.* do not use the end divisions of the rule inasmuch as they are apt to be worn). Estimate with the eye fractions of a millimeter in tenths. Record measurements in centimeters, and tenths and hundredths of a centimeter, thus 3.47^{cm}.

Record observations and estimates as follows:

Dimensions of block of . . . . . . wood.

	Length	Width	Thickness
1 trial	. . . . .	. . . . .	. . . .
2 "	. . . . .	. . . . .	. . . .
3 "	. . . . .	. . . . .	. . . .
4 "	. . . . .	. . . . .	. . . .
Sum	. . . . .	. . . . .	. . . .
Average	. . . . .	. . . . .	. . . .

Volume = (Indicate mathematical operation.)
Mass =
Density = (Indicate mathematical operation.)

20.

Ap.: micrometer caliper (Fig. 1*a*), piece of window glass about 3 × 2 in., and an iron wire, No. 16, 25 cm long, balance and set of weights.

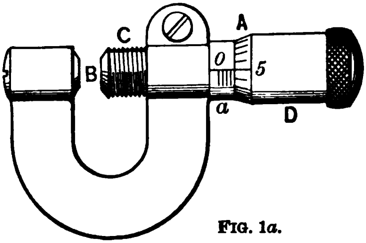

FIG. 1*a*.

Place the piece of glass in the jaws *B* of the caliper and turn the thimble *D* so as to close the jaws and *gently* pinch the glass. Ascertain the thickness of the glass at this point. The pitch of the screw *C* is one millimeter (*i.e.* in one revolution of the screw it advances one millimeter), and the thimble *D* is divided near its end *A* into one hundred parts so as to register hundredths of a revolution or of a millimeter. Read the millimeters on the scale *O*, and read the hundredths of a millimeter on the scale *A* noting the point where the horizontal line *O* (parallel with the axis of the screw) meets the scale *A*. For example the jaws of the screw in Fig. 1*a* are open 4.05 millimeters, which is the thickness of any article which would just fill the gap *B*.

Measure the thickness of the glass at ten different points at least. Record each result and from these results obtain the average thickness.

21.

With the caliper, measure at intervals of about 3^{cm} the thickness of the iron wire. Ascertain the average thickness of the wire.

22.

Ap.: balance, set of metric weights, 1 kilo down; brass, copper, and iron wire, No. 30; ap. as in Fig. 2, consisting of two rods of wood, *A* and *B*, and a tin basin, *D*.

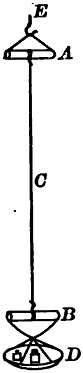

FIG. 2.

a. Weigh rod, *B*, with the pan, *D*. Take a piece of one of the three kinds of wire, about 80^{cm} long, wind at each end two or three turns centrally around each of the wooden rods. Suspend from hook, *E*, so that the pan, *D*, will clear the table a few inches.

Place in the pan about 250^{g}. Then add 10^{g} at a time, laying the weights carefully in the pan, until the wire breaks. Ascertain the force, including the weight of *B* and *D*, necessary to break the wire, and determine therefrom its ***tensile strength.***

b. Repeat the experiment (twice if there is more than 20^{g} difference in the two results) with another piece of wire.

c. Determine the tensile strength of each of the other kinds of wire in the same manner.

d. Tabulate the results, giving the averages as ascertained by different trials with each kind of wire.

23.

Ap.: straight glass tubes about 4 in. long, with bores varying from $\frac{1}{32}$ in. to $\frac{1}{8}$ in. in diameter, and a tumbler full of water. [These tubes should be cleaned frequently by thrusting them into nitric acid and then rinsing in water, and finally thrusting them into a dilute solution of caustic soda or potash and rinsing again in water.]

a. Take two tubes, suck the water out of the bores, if they contain any, thrust them vertically and very slowly into the water to about one-half their length; then very slowly draw the tubes up and out of the water, observing carefully all phenomena throughout the experiment. Repeat the experiment with one of these tubes and another tube, and so continue until you have employed as many pairs as possible.

Briefly describe the phenomena which you observe.

b. Do you discover any relation between the relative hights of the water in the tubes (while thrusting them into the water, drawing them out, and after they are withdrawn) and the diameters of their bores, as nearly as you can measure with your eye?

c. When the tube leaves the water, what phenomena do you observe?

24.

Ap.: small beaker containing mercury and the same glass tubes used in Ex. 23.

a. Dry the tubes thoroughly, thrust them vertically into the mercury, and observe all phenomena.

b. State what phenomena are the reverse of those which occurred when the tubes were thrust into and taken out of water.

c. Why are these phenomena reversed?

d. Why are drops of both water and mercury, likewise drops of all liquids, spherical (more properly, spheroidal)?

25.

Ap.: two U-shaped tubes (one arm of each tube having a capillary bore, the other arm not having a capillary bore), one about half-full of water and the other about half-full of mercury. Both tubes should be so supported by clamps, or otherwise, as to leave all the liquid surfaces easily visible. The tubes should be placed between the experimenter and a window.

a. Make drawings of vertical sections of both tubes, including the liquids in both arms, being careful to represent faithfully the relative hights of the liquids in both arms of the tubes respectively, and the shapes of the free surfaces of the liquids.

b. Why is not the water as high in the large arm as in the small arm?

c. Why is the mercury lower in the small arm than in the large arm?

26.

Ap.: tumbler full of water, small cambric needle, and an oily cloth.

a. Wipe the needle with the cloth and carefully lay it on the surface of the water, so that it will float.

How is the surface of the water changed where the needle lies?

b. Steel, of which the needle is made, is heavier than the same volume of water; what, then, prevents the needle from sinking, and why should not all bodies of steel float?

DYNAMICS OF FLUIDS.

27.

Ap.: glass flask with stopper, through which passes a glass tube reaching nearly to the bottom of the flask. The tube projects above the stopper about 3 in., and is drawn out so as to allow only a very fine stream to pass through it.

a. Put water into the flask so as to cover the end of the tube about an inch. Blow all the air into the bottle possible from the lungs through the tube, and cover the end of the tube with the tongue to prevent the escape of air. When ready, withdraw the tongue. What happens?

b. What property does this phenomenon show that air possesses?

c. Is it the weight of the air in the flask that causes the water to escape, or is it the elastic force of the air due to its compression?

d. When the stream ceases, does the water in the tube settle to the level of the water in the flask?

e. Where is the expansive force of the air greater now, inside or outside the flask?

f. Estimate the difference in pressure of the two airs per square centimeter, reckoning 1^g for every centimeter the water surface in the tube is higher or lower than the water surface in the flask. [Find by inserting the tube in an open vessel of water what allowance should be made, if any, for capillary action.]

28.

Ap.: ordinary test-tube of very thin glass (better of large diameter) and a dish of water.

Thrust the tube into the water, with the closed end downward, until the water is within $\frac{1}{8}$ to $\frac{1}{4}$ in. of the open edge. You feel the upward pressure or buoyant force of the water. Hold the tube steady in this position, resting your arm on the edge of the dish, and pour water slowly into the tube until the upward pressure is just overcome. What principle is approximately verified by this experiment?

29.

Ap.: two hydrometer jars about 15 x 2 in., filled with water, a meter-stick, two bent glass tubes containing mercury in the U-bend. The long arm of one tube, Fig. 3, is plunged nearly its entire length into the water; the long arm of the other tube (Fig. 4) is inserted to a depth of only 6 or 8 in.

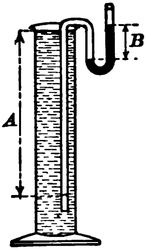

FIG. 3.

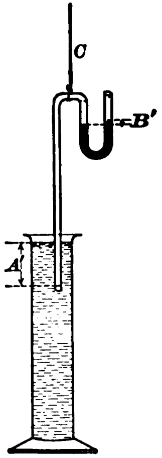

FIG. 4.

a. Measure the vertical distance, A, between the two water surfaces; also the vertical distance, B, between the two mercury surfaces. Measure also the vertical distances, A' and B'. Tabulate your results.

b. What does the water in the tube press against, and in what direction does it press?

c. What transmits the pressure to the mercury?

d. What represents the magnitude of this pressure?

e. Test the proportionality between the numbers representing the different depths in the water and the numbers representing the corresponding pressures; *i.e.* is $A : A' :: B : B'$?

f. If the foregoing quantities are proportional, then frame a law which will express the relation, thus: *The upward pressure* [illegible] *of liquid varies,* etc.

30.

Ap.: glass jar, nearly filled with water; glass tube, bent as in Fig. 5, containing water in the bend; meter-stick, and some splinters of wood. The tube is suspended so that the ends will be submerged in the water.

a. Measure the distance, *AB*; also (by thrusting splinters down beside the tube) the depths, *CD* and *EF*. Find the difference between the two depths.

b. How does the difference between the two depths compare with the distance, *AB*?

c. What does this show with reference to upward pressure at different depths?

d. If the tube were thrust down deeper in the water, would the distance, *AB*, be changed? Why?

e. How does the density of the air in the long branch, *G*, compare with that in *H*? Why?

f. In which branch is the expansive force of the air greater? What serves as a gauge of the difference in the expansive force of the air in the two branches?

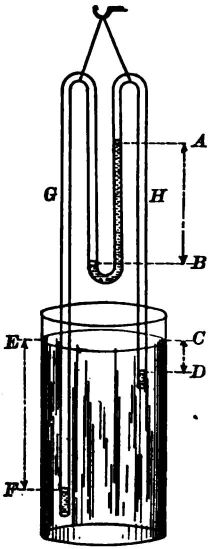

Fig. 5.

g. Estimate the difference in the expansive force of the air in the two branches in grams per square centimeter.

h. Calculate the upward pressure at the depth, *F*.

31.

Ap.: glass Bunsen battery cup, *A* (Fig. 6), partly filled with water; glass T-tube, *B*, with rubber tube and clamp, *C*. Connected with the T-tube by rubber connectors are a glass tube, *E*, of small bore, and a tube, *D*, of large bore, but drawn out small at its upper end.

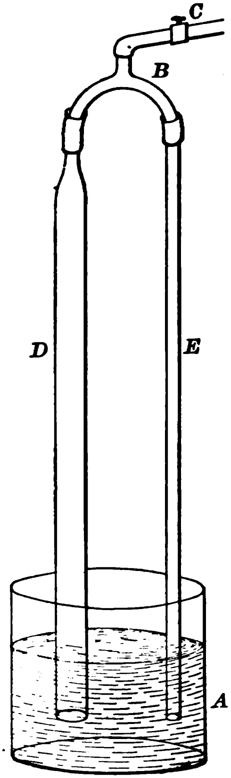

FIG. 6.

Is the hight of a column of liquid which atmospheric pressure sustains independent of the size of the column?

Thrust the tubes into the water and suck some air out, and clamp the rubber tube at *C*. Conclusion, and how reached.

32.

Ap.: meter-stick, straight barometer tube, and small shallow cup (crockery or glass) of mercury. The tube has been filled with mercury (care being taken to expel all air bubbles adhering to the interior of the tube), and then inverted and inserted in the cup of mercury and supported by a ring-stand and clamp.

a. Measure to the nearest millimeter the hight of the barometric column. State the date and hour at which the observation is made.

b. When next you work in the laboratory, repeat the observation, giving date and hour.

c. Calculate the atmospheric pressure at the time of each observation.

33.

Ap.: **Mariotte's tube (Fig. 7), mercury, measuring-stick, and barometer (Fig. 7*a*).**

If it be true that "the volume of a body of gas varies inversely as its pressure," or elastic force, then it follows that the product (VP) of these two quantities must have a constant value. *Test it.* Let the mercury be at the same level, AB, in both arms of the tube. The body of air to be experimented with is in the short arm between A and C. The dimensions of this body can vary only in hight; hence its hight, H, may represent its volume. Measure its H, *i.e.* the distance between A and C, and regard the number of inches (or centimeters) as representing the volume, V. Its pressure, P, evidently is the same as that of the atmosphere at the time of experimenting. Consult the barometer and ascertain the hight of the barometric column; let this hight represent P. Pour a little mercury into the tube; the mercury rises to A_1 and B_1. Measure from A_1 to C; this number represents the volume, V_1, of the body of gas now. Measure the vertical distance between A_1 and B_1; this number represents the increase in pressure, which, added to P, will give its present pressure, P_1.

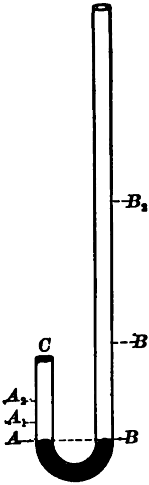

Fig. 7.

Fig. 7a.

Now pour more mercury into the long arm, so that it will rise to some such points as A_2 and B_2. Determine as before the new volume, V_2, and new pressure, P_2. So continue to add mercury a third, and a fourth time, and get new values for the volume, V_3, and V_4, and for the pressure, P_3, and P_4. Arrange your results as follows: —

$V =$	$P =$	$V \times P =$
$V_1 =$	$P_1 =$	$V_1 \times P_1 =$
$V_2 =$	$P_2 =$	$V_2 \times P_2 =$
	etc.	etc.

34.

Ap.: vacuum gauge, Fig. 8 (having the closed arm and a small portion of the other filled with mercury), an ordinary barometer, and an air-pump and tall glass receiver.

a. Measure the maximum exhaustion, in percentage, attainable with your pump. Place the vacuum gauge under the receiver of the air-pump and centrally on the plate. Grease the edges of the receiver all around with vaseline, place it on the plate, and by a twisting motion grind it tightly on to the plate. Pump rapidly, taking full-length strokes, as long as the mercury sinks in the closed arm. Measure the vertical distance between the highest points of the two surfaces of mercury in the two arms in millimeters. Ascertain, by consulting the barometer, the hight of the mercurial column which the atmosphere sustains at the time and place. From these data compute the extent of the exhaustion in a percentage of the existing atmospheric pressure.

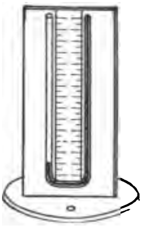

FIG. 8.

b. On the assumption that a mercurial column of 760^{mm} indicates a pressure of 1033.3^{g} per square centimeter, calculate the pressure per square centimeter within the receiver.

c. Measure the internal diameter of the circular aperture of the receiver. Calculate the area of a cross-section of the receiver at this part. The adhesion between the rim of the receiver and the plate and the weight of the receiver being disregarded, the unbalanced force which holds the receiver on the plate is the difference in pressure which would be exerted upon the opposite sides of a circular disk having this for the area of one of its sides, the rate of pressure being the same as determined by the barometers outside and inside the receiver.* Calculate the force necessary to separate the receiver from the plate.

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* ee Magdeburg Hemispheres, Gage's Physical Technics, p. 88.

35.

Ap.: Seven-in-one ap. and rule.

a. Open the stop-cock, *B* (Fig. 9), and force the piston into the hollow cylinder as far as possible; then close the stop-cock and see if you can draw the piston out. Open the stop-cock and see if you can draw the piston out. Explain the difference observed in the two cases.

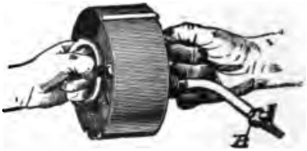

Fig. 9

b. Measure in inches the interior diameter of the hollow cylinder or the diameter of the piston. On the supposition (which is not true) that when you force the piston in as far as possible you force all the air out through the tube, leaving none in the cylinder back of the piston and none in the tube, calculate what force will be required to pull the piston out on a day when the barometric column stands at 30 in.

c. There is, however, a little space for air back of the piston when pushed in, and the tube is filled with air. Should you succeed in pulling the piston out a little way, how would the density and expansive force of this remnant of air be affected? Would this tend to increase or decrease the difficulty of drawing the piston out still farther?

d. Should you succeed in drawing the piston out so that the imprisoned air would occupy four times the space which it originally occupied, how much force would be required to start the piston from this position (disregarding friction)?

36.

Ap.: a glass U-tube, each arm 30 in. long and about ¼ in. bore, having a rubber tube 2 ft. long attached to one end of the tube (the tube contains mercury to the depth of about 14 in. in both arms), and a rule containing inch divisions.

Ascertain the maximum pressure per square inch which you can exert by blowing from the lungs. Blow through the rubber tube gently at first, increasing the pressure gradually until it reaches a maximum; pinch the rubber tube and rest for a short time; then blow again as before till the mercury is raised as high in the opposite arm as it is possible to sustain it for a few seconds. Note the highest point reached by this surface and the lowest point reached by the surface against which you blow. Measure the vertical distance between these two points. Reckoning for each inch in difference of level of the two surfaces a pressure of 0.5 lb. per square inch, find the greatest pressure that you can exert.

37

a. Ascertain the force of suction (so-called) *which you can exert.* Suck with your mouth as much air out of the arm of the tube to which the rubber tube is attached as you are able; measure, as in the last experiment, the vertical distance between the two mercury surfaces, and calculate in the same manner the suction force which you can exert per square inch.

b. Inasmuch as there is no such thing as a suction force (though the expression is a very convenient one), explain the phenomenon produced by suction and state the origin of the unbalanced force which raises the mercury in the arm where the suction takes place.

38.

Ap.: seven-in-one ap. and inch rule.

a. Measure the diameter of the piston, determine the area of one of its circular surfaces, and calculate the pressure which you can exert upon the piston by blowing through the rubber tube, making use of the number representing the pressure which you are capable of exerting, as found in Ex. 36; in other words, ascertain how heavy a weight placed upon the piston you could raise if the latter were weightless and frictionless.

b. Calculate how heavy a weight suspended from the piston could be raised by suction (using the number found in Ex. 37) if the piston were weightless and frictionless.

39.

Ap.: seven-in-one ap. (Fig. 10) and metric rule.

a. Measure the diameter of the bore of the rubber tube (where it has not been stretched) and the diameter of the piston in the hollow cylinder, and determine the areas of each. Suppose the rubber tube to be raised so that its upper end is kept 3^m (10 ft.) above the bottom of the piston, and that water should be poured into the tube so as to fill it; calculate the weight of that portion of the water in the tube that would be available in exerting an upward pressure against the piston.

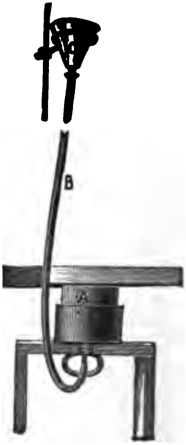

FIG. 10.

b. Calculate in kilograms the total upward pressure that would be exerted on the piston and find its equivalent in pounds.

40.

Ap.: seven-in-one ap., 16 lb. weight, and spring balance.

a. Insert the handle in the piston, attach to it the spring balance, and measure the force necessary to start the piston; *i.e.* the friction between the cylinder and piston. Remove the handle and place a (say) 16 lb. weight on the piston (do not allow the weight to touch the interior of the cylinder so as to scratch it). Blow through the tube and raise the weight. Add to the weight of the body raised the friction overcome, and determine the entire upward pressure which must have been exerted on the piston in order to move it.

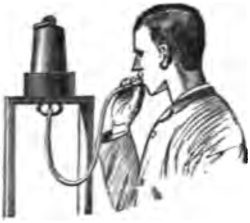

FIG. 11.

b. Knowing the areas of the bottom of the piston and a cross-section of the bore of the tube, calculate the force in ounces or pounds exerted by the lungs through the body of air in the tube; *i.e.* the force exerted against a cross-section of the air in the tube when the piston is moved.

41.

Ap.: glass U-tube, each arm about 12 in. long and $\frac{1}{4}$ in. bore, half full of water, and a metric rule. One end of the tube is connected by a rubber tube with a gas-pipe nipple.

Turn the gas stop-cock and allow the gas to enter the tube and press upon the water in one of the arms. As soon as equilibrium is established, ascertain the vertical distance between the two water surfaces in the two arms to the nearest millimeter, and determine how much greater the pressure of the gas is per square centimeter than the atmospheric pressure.

42.

a. Copy the diagram in Fig. 12, enlarging it to double size.

b. Let the diagram represent a transverse vertical section of a tank filled with a liquid. The bottom of the tank is square. By broken lines represent a vertical section of a volume of the liquid whose weight is the downward pressure of the liquid on the bottom of the tank. Construct the section on *BC* as one of its sides.

c. On *AB* construct, with broken lines, a rectangular figure, which will represent a vertical section of a volume of liquid, whose weight is equal to the pressure exerted by the liquid on this side.

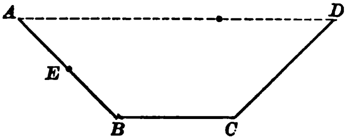

FIG. 12.

d. Draw a line, inserting an arrow-head, meeting the line, *AB*, at some point, as *E*, which shall represent the direction in which the liquid exerts pressure on this side.

43.

Ap.: rectangular tank, filled or partially filled with water (a large wooden box, of dimensions suited to the laboratory, lined with zinc, having the joints soldered, is a great convenience in a laboratory in many ways, though for this experiment the small zinc pneumatic trough used by pupils in the chemical laboratory will answer), and a meter and yard-stick. A rectangular figure should be marked or painted on the exterior surface of one of the sides of the tank.

a. Make suitable measurements with the meter-stick (*without wetting it*), and find the pressure of the water in kilograms on the bottom of the tank.

b. Convert this pressure into pounds (see Table of Equivalents).

c. Make suitable measurements with the yard-stick, and compute the pressure of the water on the bottom of the tank in pounds.

d. State the discrepancy in the last two estimates.

44.

a. Make suitable measurements, and compute the pressure exerted by the water upon one of the sides, or one of the ends, of the tank.

45.

b. Make suitable measurements, and compute the pressure exerted by the water on a portion of the interior surface of the side of the tank, exactly opposite, and of the same dimensions as the rectangular space marked thereon.

c. If the liquid were sulphuric acid, what would be the pressure upon this space?

d. What is the volumetric capacity of the tank in cubic feet or cubic inches? in gallons?

e. What mass of water will the tank hold when even full?

46.

Ap.: four tumblers containing clean water, and four bent glass tubes, arranged and suspended as in Fig. 13. The tubes are filled with water.

a. Suck water at *E* until, when the water is at rest, each of the tumblers is about one-fourth full. *Do not at any time allow the surface of the water in D to fall as low as the ends of the tubes in that tumbler.* Observe and explain the phenomena which occur.

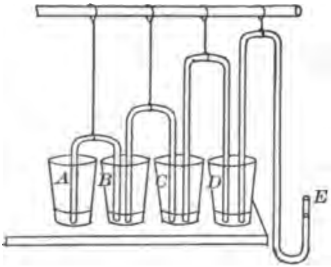

Fig. 13.

b. Then fill *A* to the brim with water and state what occurs.

c. When the water again comes to rest, fill *D* to the brim and state what occurs.

d. What appears to be the necessary condition on which water will flow from vessel to vessel?

e. Does the water in any case flow "up hill"; *i.e.* from a lower to a higher level?

47.

Ap.: balance, weights, jar of water, Archimedes ap., and a lipped beaker.

a. Place the solid cylinder into the hollow cylinder, technically called "the bucket." How does the volume of the cylinder compare with the capacity of the bucket ?

b. If the cylinder were submerged in water, the water displaced by it would fill what portion of the bucket ?

c. Wipe the bucket dry inside and outside; likewise wipe the cylinder. Suspend by a short thread the cylinder from the hook beneath the bucket, and suspend the bucket from the hook beneath the scale-pan. Counterbalance the whole with sand, weights, or other convenient body, placed in the opposite scale-pan. Place the cylinder in the jar of water so that it will be completely immersed, as shown in Fig. 14. Do not allow the bucket to touch the water or to become wet. To prevent this, the left hand should be kept on or near the balance beam throughout the experiment. How is equilibrium destroyed by the immersion ?

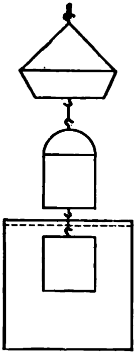

FIG. 14.

d. Pour water from the beaker slowly into the bucket, without wetting the outside, until equilibrium in the balance beam is restored. As you approach this point, the liquid should fall from the beaker a drop at a time.

e. The buoyant force exerted upon a solid immersed in a liquid is equal to the weight of what volume of that liquid ? How does this experiment illustrate your statement ?

48

Ap.: balance with hook under one of the pans, set of weights from 10^g to 1^{cg}, tumbler of water, and small bodies (3 to 6^{cc}) of various substances.

From the hook beneath the scale-pan (Fig. 15) suspend by a fine thread a small body of a substance whose specific gravity is to be found, and weigh it, while dry, in the air. Then immerse the body in a tumbler of water (do not allow it to touch the tumbler, and see that it is completely submerged) and weigh it in water. While weighing, use the left hand to steady the balance beam on its support, and to prevent the pan from touching the water beneath. Record the weights (in grams and hundredths of a gram) as soon as found, at the top of the page. Indicate below the mathematical operations, and still lower on the page tabulate the results. The arrangement is as follows:

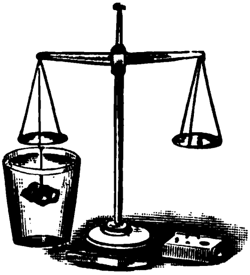

FIG. 15.

	Wt. in air	Wt. in water	Loss
Quartz	....	....	....
Marble	....	....	....
Zinc	....	....	....

Sp. gr. of Quartz $= \frac{....}{....} = ...$

" " " Marble $= \frac{....}{....} = ...$

" " " Zinc $= \frac{....}{....} = ...$

	Sp. gr. as found	Sp. gr. as per table (p. VIII)	Difference.
Quartz	....	....	......
Marble	....	....	......
Zinc	....	....	......

49.

Ap. : rectangular block of wood such as used in Ex. 19, piece of sheet lead about 1¼ in. long and ¼ in. wide to be folded about the block of wood for a sinker, balance, weights, metric ruler, tumbler of water.

Obtain and record data as follows:

I.

Dimensions of block of . . . . . wood : length . . . , width . . . , thickness . . . .

Volume = ... × . . . . . × . . . . . = ...^cc; mass = ... ; density of . . . . . wood = ... ÷ . . . . . = ...

II.

Wt. dry block in air . . . .
“ “ sinker “ “ . . . .
“ sinker in water . . . .
“ water displaced by sinker . . . .
“ block and sinker in water . . . .
“ water displaced by both . . . . .

Wt. water displaced by block . . . .
Sp. gr. of the block . . . .
Density of . . . wood = . . . ÷ . . . = . . .
Difference of density as found by the two methods . . . .
Sp. gr. of lead . . . .

50.

Ap.: specific-gravity bottle and counterpoise, balance, weights, distilled water, and some granular or friable matter; *e.g.* dry sand, clay, earth, etc.

Weigh a portion of the given solid, enough (say) to about one-fourth fill the bottle; make a conical-shaped tunnel of paper that will just fit the neck of the bottle; pour the matter into the bottle and fill the bottle with water; place the bottle scale-pan and its counterpoise on the other, and on one weigh the contents of the bottle. The difference between this weight and the sum of the weights of the solid and the water which the bottle is capable of holding is the weight of the water displaced by the solid. Compute the specific gravity of the solid.

51.

Ap.: as shown in Fig. 16, consisting of a three-way glass tube, *A*; two glass tubes, *B* and *C*, each about 2 ft. long; three short pieces of rubber tubing, two of which are used for connectors, and one is applied to the free end of *A*; two tumblers, one containing distilled water, and the other a liquid whose density is to be compared with that of water; a clamp or string; and a measuring-stick.

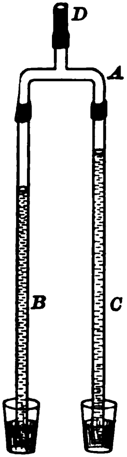

FIG. 16.

a. Introduce the tubes, *B* and *C*, into the two liquids, suck air from the extremity, *D*, until one of the liquids has risen nearly to one of the rubber connectors, then clamp the rubber tube, *D*, or tie a string tight about it so that air cannot enter. Measure the elevation of the liquid in each of the tubes, *B* and *C*, above the surface of the liquids in the tumblers.

b. How is the liquid in the two tubes sustained?

c. Why is the liquid in one tube higher than in the other?

d. Compare the densities of the two liquids stating which is denser.

52.

Ap.: demonstration hydrometer, *H* (Fig. 17), consisting of a prism of paraffined wood, ½ in. square and 5 in. long, with inch and quarter inch divisions, and loaded so as to assume a vertical position when placed in a liquid; beaker of water, and beakers of other liquids, each beaker having a label with the name of the liquid on it.

a. Lower *H* into water: it sinks to the number 4, displacing how many cubic inches of water?

b. Rinse *H* with water, wipe, and lower it into one of the other liquids. Note carefully the depth to which it sinks, dividing with the eye each division into quarters (sixteenths of an inch). What volume of this liquid does *H* displace?

c. Is this liquid denser or rarer than water?

d. Calculate from the data obtained the specific gravity of the liquid last used.

e. Never fail to rinse *H* thoroughly with water and dry it with a cloth after using it. Determine in the same way the volume of each of the other liquids displaced by *H* and the specific gravity of the liquid. Tabulate the results of all the experiments.

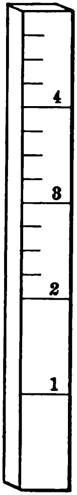

FIG. 17.

53.

Ap.: hydrometer jar, containing some liquid (*e.g.* solution of common salt, alcohol, sulphuric acid, etc.) whose specific gravity is to be found, and hydrometers for heavy and light liquids. The hydrometer stands in the liquid.

Read the specific gravity of the liquid on the stem of the hydrometer at the point where the surface of the liquid would meet the stem if the surface were not turned up around the glass stem.

54.

Ap.. balance (Fig. 18); specific-gravity bottle, filled with some liquid whose specific gravity is sought; counterpoise of the empty bottle, and weights.

Place the bottle on one of the scale-pans, and on the other pan the counterpoise. Find the weight, G, of the liquid in the bottle. The weight, G', of an equal volume of water is engraved on the bottle. Find the specific gravity of the liquid, and tabulate the results as before.

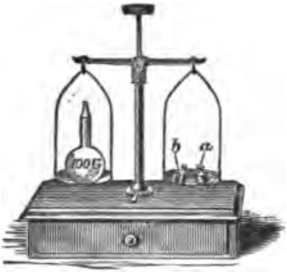

FIG. 18.

55.

Ap.: tumbler nearly full of a liquid (*e.g.* solution of common salt, saltpetre, sulphate of copper, etc.) whose specific gravity is sought, another tumbler to be nearly filled with fresh water, small pebble (*e.g.* quartz), balance (Fig. 15), and weights.

Find the loss of weight, G, of the pebble when submerged in the given liquid. Rinse the pebble in clean water, wipe it, and find its loss of weight, G', when submerged in water. From these data determine the specific gravity of the given liquid, and tabulate the results as before.

56.

Ap.: pebble whose volume is sought, tumbler of water, balance (Fig. 15), and weights.

Find the volume of the pebble. Its loss of weight in grams when submerged in water is numerically equal to its volume in cubic centimeters.

GENERAL DYNAMICS.

57.

Ap.: metric rule.

a. Fix the points of compass on the blank page opposite by drawing two intersecting lines at right angles to each other and appropriately lettering their extremities, N. S. E. and W.

On a scale of 1^{cm} = (represents) 1 ft., represent a motion, toward the east, of 8 ft. (Put an arrow-head in the line.)

b. On the same scale represent a motion, northwest, of 10 ft.

c. On a scale of 1^{cm} = 1 lb., represent a force of 7 lbs. acting toward the west.

d. Draw in any direction a straight line of any desired length. On the scale given in *c*, determine the magnitude of a force which this line would represent.

58.

Ap.: see Fig. 19.

a. Composition of forces acting parallel with one another. Support the beam at the side-central hole in the bushing by means of pulley, pan, and weights, as in Fig. 19; bring the beam into equilibrium by moving the balls at the end of the beam. Choose points on the beam at unequal distances from the point where the beam is supported, for the points of application of two parallel forces; calculate what the relation between the magnitude of these two forces must be in order that the forces may be in equilibrium with each other.

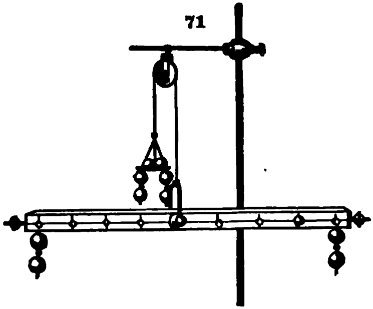

Fig. 19.

b. Calculate what additional force must be applied at the pan as an equilibrant of these two forces.

c. Verify both calculations by the application of suitable weights.

d. Draw a horizontal line, on a scale of $\frac{1}{4}$ of 1 in. = 1 space on the beam, on the opposite page, to represent the beam. Locate on this line, by the letter *E*, the point of application of the equilibrant; locate by *F* and *F'* the points of application of the two forces of which the above is an equilibrant. From each of these three points draw lines to represent correctly the direction and intensity of each of the forces acting at the respective points (*e.g.* a line $\frac{1}{4}$ of 1 in. long may represent one of the equal weights used), and insert an arrow-head in each line to indicate the direction in which each force acts.

e. Find and express the moments of the two forces which act in the same direction, and state the reason that these two forces are in equilibrium.

f. State the laws of parallel forces which this experiment illustrates.

59.

Draw a horizontal line 8^{cm} long to represent a body. On a scale of $5^{mm} = 1$ lb. represent a force of 8 lbs. applied at one extremity, *A*, of the body and acting toward the north. Represent another force of 12 lbs. applied at the other extremity, *B*, of the body, and acting in the same direction. Determine the point, *C*, of the application of the resultant, draw a line, *CD*, to represent their resultant, and draw another line, *CD'*, to represent their equilibrant.

60.

Ap.: as in Fig. 20.

Principle on which scale-beams for weighing are constructed.

a. Place the axle in the center hole of the brass bushing and move one of the balls, *A* and *C* (if necessary), until the beam is exactly balanced when in a horizontal position. Then place the beam in various oblique positions and ascertain whether it is balanced in the different positions.

b. Place the axle in the hole of the bushing, a little to one side of the central hole. Repeat the aforementioned operations and note any difference in the results.

c. Where is the center of gravity of the beam?

d. When the axle is in the central hole, in what kind of equilibrium is the beam?

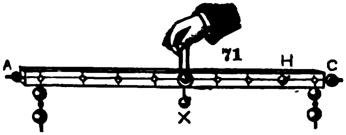

Fig. 20.

e. Place the axis in the central hole again and introduce the pin, *X* (with ball on the end), into the hole in the beam on the lower side; place equal weights on equal arms of the beam, tilt the beam and find what position the beam now tends to take.

f. Where is the center of gravity now with reference to the point of support?

In what kind of equilibrium is the beam now?

g. Thrust *X* through the side hole, which should be under the central hole. The effect of this is to raise the center of gravity a little. See if this makes the beam any more ***sensitive*** ; *i.e.* more susceptible to being moved from a horizontal position.

h. Place *X* in the hole in the beam, as in Fig. 20; turn the beam over so that *X* will be above the beam. (1) Is the center of gravity now below or above the point of support? (2) In what kind of equilibrium is it now? (3) Ought a scale-beam to be constructed in this manner? Why?

i. Observe that the center of gravity of the beam when *X* is removed is in a straight line, connecting the points of application of the weights to the beam. This being the case, where should the point of application of the support be placed, in order to construct an efficient and sensitive balance, *i.e.* above or below the center of gravity of the beam, a very little distance or a greater distance from the center of gravity?

j. Examine the balances used in finding specific gravity and see if this principle appears to be observed in its construction.

61.

Ap.: linen thread 10 in. long, with small loop in the middle with which to make a slip noose; a spindle, terminating in a sharp point; and a metal arc, with ball attachments, as shown in Fig. 21.

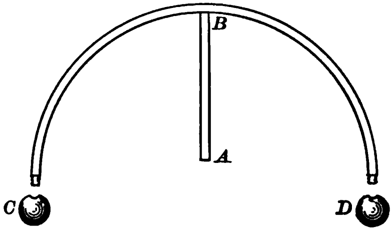

FIG. 21.

a. Lay the arc upon your blank page, and make an accurate diagram of it by running the fine point of a pencil along its edges.

Attach a small weight to one end of the thread; apply the thread by means of slip noose at some point of the arc, and suspend the whole from the hand, grasping the free end of the thread, and note carefully the two points where

the thread crosses the arc when at rest. Locate these points accurately on your diagram, and draw a straight line through them, crossing the bar, *AB*. Suspend, in the same manner, the arc from at least three other points, and get the line of direction in each position and locate it on your diagram as before. Do the four lines have a common point of intersection?

b. When you have found a common point of intersection, place the spindle point at the point (in the bar) corresponding to it, and see if the bar is supported and balanced at this point.

c. Apply the point to opposite sides of the bar and see whether the arc is as easily balanced in both cases. If you find any difference, explain it.

d. (1) How would you support the arc on the point so that it would be in stable equilibrium? (2) Unstable equilibrium? (3) Where would you perforate it and insert the spindle that it would be in indifferent equilibrium?

e. Screw the balls, *C* and *D*, on to the ends of the arc, and again suspend; find, and locate on your diagram its new center of gravity.

f. See if you can support the arc on the point applied at the end, *A*, of the bar. If so, determine the kind of equilibrium and explain the same.

62.

Ap.: loaded circular board, *A* (Fig. 22); spindle, *B*; plumb-line; inclined plane; and measuring-stick.

Suspend the plumb-line from the spindle and thrust the spindle through the hole, *a*, of the board, *A*, and ascertain the line of direction of the board when supported at this point. Find, in the same manner, the line of direction when supported at *b*, and thereby determine the center of gravity of the board.

63.

Thrust the spindle through each of the holes, *a*, *b*, *c*, and *d*, and cause the board to rotate about each as a center. About which does the board rotate easily and freely, for the longest time, and with the least drag on the axle? Where is the center of magnitude of this body? Where is its center of gravity? Where is its natural center of motion? Which two of these three centers always coincide? When do all three centers coincide?

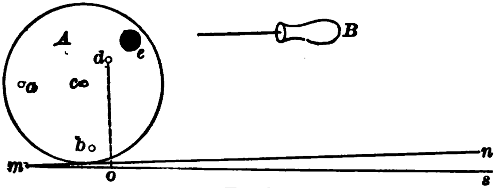

FIG. 22.

64.

Place the board, *A*, on a board, *mn*, a little inclined and in a position as nearly as practicable like that shown in Fig. 22. Remove your hand from the board, *A*; it rolls along the inclined plane: why?

The board rolled up the inclined plane; did the body ascend or descend, *i.e.* did its center of gravity ascend or descend? To determine this, place the body again in the original position, and close to the nearest edge of the inclined plane, measure the hight of the center of gravity of *A* above the desk (*i.e.* *d o*); then let it roll and measure the hight of the center of gravity again and determine just how much the body (*i.e.* its center of gravity) ascends or descends in rolling along the inclined plane.

65.

Ap.: Same as shown in Fig. 23; also measuring-stick, Harvard balance, and weights.

Verify the principle that ***when several forces, acting in the same plane on a body, in directions parallel with one another, are in equilibrium, the algebraic sum of their moments is zero.***

a. The force of gravity acting directly on the rod is one of the forces to be considered. Remove the weights and find the intensity of this force by weighing the rod. Find the point of application of this force (*i.e.* its center of gravity) by balancing the rod on a knife-edge and mark this point on the rod.

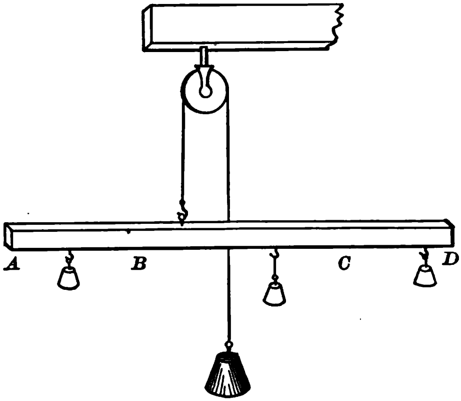

FIG. 23.

Replace the weights, as shown in Fig. 23. Take some point on the stick (*e.g.* *A*, *B*, *C*, or *D*) as a point of reference, "fixed point," or point in the axis of rotation. Find the moment of each of the *five* forces applied to the rod, taking for the leverage of each force the distance of its point of application from the point of reference. Apply the proper sign to each moment and find their algebraic sum.

b. Determine the kind of equilibrium which the rod, together with the several weights attached to it, has, and state what your test is.

c. State the reason for its having this kind of equilibrium.

d. Show that the equilibrant of the several parallel forces, acting vertically downward upon the rod, is equal to the sum of the components.

66.

Ap.: A protractor and a metric rule.

Two forces of 00 (supply a number) lbs. and 00 lbs. act at an angle of 00 degrees; represent on a scale of 00 = 1 lb. the equilibrant of these forces, and express its intensity numerically.

67.

Choose, arbitrarily, a scale (stating what it is); draw a diagram to represent the composition of three forces acting angularly with one another, and express numerically the intensity of each component and their resultant.

68.

On a scale of $5^{mm} = 1$ lb. draw a line to represent a force of 14 lbs. Resolve this force into two forces, one of which shall be 8 lbs. and shall act at an angle of 42° with the line which represents the force to be resolved.

69.

Scale $\frac{1}{4}$ of 1 in. = 1 knot. Fix the points of compass $\left(\text{thus, } \mathrm{W}\overset{\mathrm{N}}{\underset{\mathrm{S}}{+}}\mathrm{E}\right)$ on your blank page. Draw a line to represent the velocity of a vessel sailing S.S.E. (*i.e.* at angle of 22.5° E. of S.) at a rate of 14 knots per hour. Determine the southerly and the easterly velocity of the vessel; *i.e.* resolve its velocity into two velocities, one due S. and the other due E., and determine the magnitude of each.

70.

Ap.: portable blackboard, with holes in the frame for insertion of pegs; two spring balances, meter-stick, and a (16 lb.) weight.

a. Place pegs in two holes; *e.g.* *A* and *B* (Fig. 24). Suspend from each a spring balance; connect the hooks of these by a string; suspend from this string another string, having a loop at one end which can be slipped along the first string at will, so that the point of application, *C*, of all the forces can be varied, and thereby the intensities and direction of the forces can be indefinitely varied. Attach the weight to the lower end of the last string. Trace upon the blackboard, or, better, upon a sheet of foolscap, the direction in which each of the supporting forces acts. Lay the paper on the opposite page of this book, prick two holes through each line, leaving indentations on the page; draw through these indentations two lines, meeting at a point, *C*. Ascertain from the balances, *x* and *y*, the intensities of the two supporting forces. Lay off on the lines to scale (state what the scale is) distances (*e.g.* *Ca* and *Cb*) to represent the intensity of these forces. Complete a parallelogram, by means of broken lines, on these two lines, and draw a diagonal to represent the resultant of these forces, and place an arrow-head in it to indicate its direction. Measure the length of this diagonal and determine by your scale the intensity of the force which it represents. Compare this result with the weight of *W*.

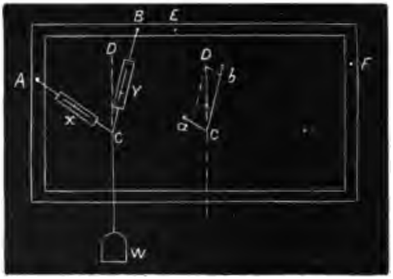

Fig. 24.

b. State the proposition which this experiment verifies, at least approximately.

c. Is the weight of *W* a resultant or an equilibrant of the two supporting forces?

71.

Ap.: table (preferably circular), with holes $\frac{3}{16}$ in. in diameter, bored at intervals of 4 in. around a circle, 2 ft. in diameter; six iron rods, 4 in. long, which fit tightly in the holes, and three or four spring balances, graduated in ounces, and some stout linen thread.

Place rods in any three holes at option; join them by threads, inserting in each of the three threads a spring balance, near to the rods, as shown in Fig. 25; stretch the spring balances so as to indicate any desired tension in the threads; place under the threads the blank page opposite; locate the point of application, *A*, of the forces on your page; draw lines (*e.g.* *AB*, *AC*, and *AD*) to represent the directions in which the forces act. Note the magnitude of each force. It is evident that any one of these three forces is the equilibrant of the other two. Select any one for an equilibrant and construct a parallelogram (*e.g.* *ABEC*) on the lines which represent the other two forces, representing accurately the relative magnitudes of these forces on some suitable scale. Draw the diagonal of the parallelogram which should represent the magnitude and direction of the equilibrant and resultant (if taken in the opposite direction) of the two forces. Measure

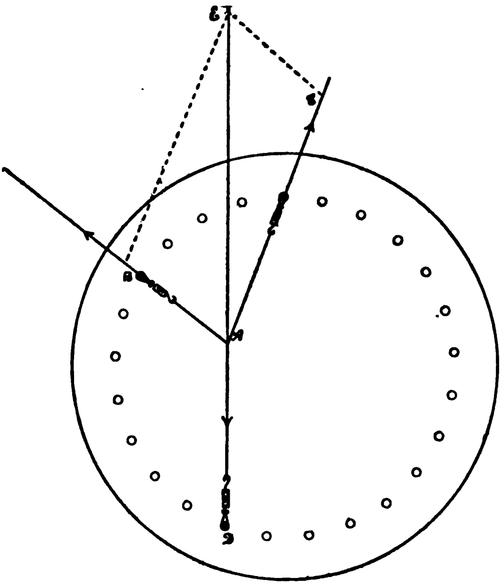

FIG. 25.

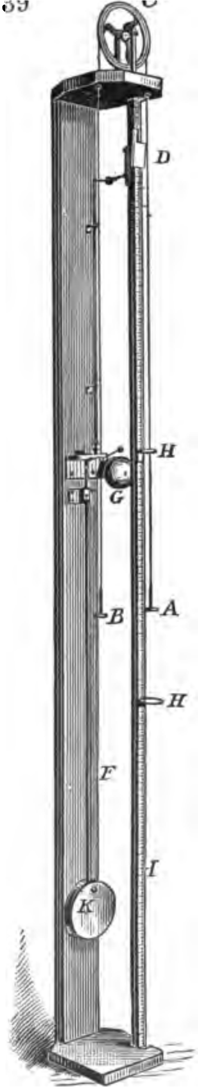

FIG. 26.

the diagonal; determine, on the scale used, the magnitude of the force which it represents; compare it with the magnitude of the force selected for an equilibrant, and state the magnitude of the error (if any).

72.

Ap.: Atwood's machine.

Verification of the Laws of Falling Bodies.

a. Let the carrier, *A* (Fig. 26), rest on the platform, *D*. Place *E* (2^g) on *A*. Set the pendulum vibrating. Raise and lower the ring, *H*, and ascertain by repeated trials the average distance the weights descend (and are caught off by the ring) between the first two strokes of the bell; *i.e.* during the first unit of time. *b.* Next find how far the weights descend during two units of time; *i.e.* between the first and third strokes of the bell.

c. Likewise find how far they descend during three units of time.

d. How far must the weights have descended during the second unit of time? *e.* During the third unit of time?

f. About how many times as far must the weights have descended during the second unit as during the first?

g. Representing the distance descended during the first unit by $\frac{1}{2}^g$, express the distances (approximately) which they descend during (1) the second and (2) the third units.

73.

a. Place H at the point which the weights usually reach at the end of the first unit, and raise and lower the other ring, H', and ascertain the distance which the carrier descends during the second unit, the weight, E, being caught off by H at the end of the first unit.

b. The unbalanced force being withdrawn at the end of the first unit, the carrier moves on during the second unit with the (uniform except so far as it is retarded by resistances) velocity it had acquired at the end of the second unit. What was its velocity at the end of the first unit?

c. It had no velocity at the beginning of the first unit; then what was the acceleration during the first unit?

d. Find the approximate acceleration during the second unit, ascertaining the velocity at the end of the second unit in the same manner as above, and deducting the velocity at the end of the first unit.

e. Calculate what the acceleration would be, if a part of the force were not exerted in overcoming friction and in generating momentum in the wheel. If $M =$ the mass of one of the carriers, and $M' =$ the mass of the rider, then the mass moved $= 2M + M'$. Let A represent the required acceleration, then $(2M + M')\ A = M'g$, whence $A = \frac{M'g}{2M + M'}$. Taking $g = 980^{\text{cm}}$, find the value of A.

f. What is the effect of a constant unbalanced force acting on a body?

74.

Ap.: Atwood's machine and accessories.

(For two pupils.) Raise the carrier, *A* (Fig. 26), and let it rest on the platform (as *D* in Fig. 27). Place a rider, *E*, weighing (say) 2^g on *A*. Set pendulum, *F*, to vibrating. Raise and lower the ring, *H*, on the graduated bar and ascertain by repeated trials the average distance the weights descend in the interval between the first two strokes of the bell (*i.e.* during first unit of time).

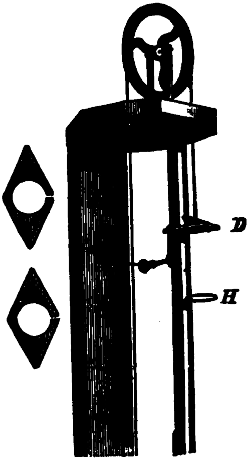

Fig. 27.

Next substitute for *E*, a weight double that of *E*. Find by trial how far the weights now descend in the same interval of time as before.

a. How great is the force which causes motion in the first instance? *b.* How many times greater is the force employed in the second instance? *c.* Are the masses moved in the two instances exactly the same?

d. Assuming that the velocity varies as the distances traversed in equal units of time, what relation does this experiment show (approximately) between the momentum generated in equal intervals of time and the quantity of force employed?

e. Neglecting errors arising from resistances, why is this only an approximate verification of the law you have just given?

75.

a. Once more place *E* (2^s) on *A* and ascertain how far they will descend between the first and third strokes of the bell; *i.e. in double the time* employed before.

b. Likewise ascertain how far they descend in treble the time.

c. How many times as far do they descend during the second unit of time as during the first? *d.* How many times as far during the third unit of time as during the first? *e.* What sources of error do you necessarily encounter in this experiment?

f. Assuming that in order to accomplish these respective distances in the successive units of time, that the velocity must vary as the time, what relation does this experiment show (approximately) between the momentum generated by a given force and the time during which the force acts?

MACHINES.

76.

Ap.: levers, etc.

Case I.: Fulcrum between the points of application of the force, *F*, and resistance, *R*.

a. Remove one of the pins in the beam near one end, thrust the axle through the hole and arrange the ap. similar to that shown in Fig. 28 (or take the side central hole in the bushing for the axle), and bring the beam into equilibrium by moving the weight, *w*, or a ball on the end of the beam. Select some point (*e.g.* 1, 2, etc., spaces), one side of the fulcrum, for the point of application of the resistance; choose a resistance (*e.g.* 1, 2, 3, 4, etc., of the equal weights); suppose it to be applied at the selected point, and calculate at what point, the other side of the fulcrum, a force equal to the weight of 1, 2, etc., balls may be applied so as to produce equilibrium with the resistance. Apply balls at the chosen points representing the resistance and force chosen, and verify your calculation. On a scale of $\frac{1}{4}$ of 1 in. = 1 space on the beam, draw a line representing the length of the beam; locate the fulcrum by the letter *f*, the point of application of the resistance by *R*, and of the force by *F*.

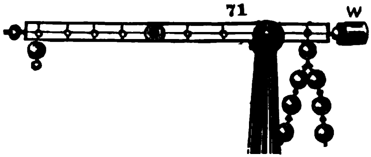

Fig. 28.

b. Show arithmetically that the moment of *F* is equal to the moment of *R*; hence the equilibrium.

c. State what mechanical advantage (*i.e.* force or velocity) is gained by your arrangement and the ratio of gain of the same.

77.

Case II.: Resistance between the fulcrum and the force.

a. Remove one of the pins in the beam near one end, thrust the axle through the hole, and arrange the ap. similar to that shown in Fig. 29. Select some point remote from the fulcrum for point of application of *F*; bring the ap. into equilibrium by applying, at the chosen point, a sufficient force by weights or sand placed in the pan, as shown in the cut. Choose some convenient number of weights for the *F*; choose the point of application of *R* nearer to *f* than *F*, and calculate what resistance *F* is sufficient to overcome; *i.e.* what the *R* is when there is equilibrium with the given force. Verify your calculation. Represent graphically this case as in the last experiment.

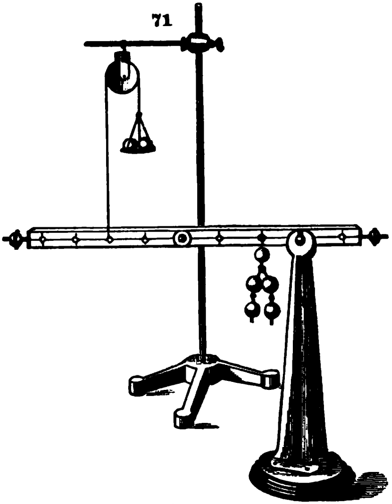

FIG. 29.

b. What mechanical advantage is gained when *R* comes between *f* and *F*; *i.e.* when the resistance arm is shorter than the force arm, and what is the ratio of advantage?

c. Express arithmetically the equality of moments in this case.

78.

a. With *f* at the same point as in the last experiment, select points of application of *F* and *R*, such that velocity may be gained, if motion is produced; *i.e.* if *F* should be greater than is necessary to overcome all resistances.

b. Apply at the point chosen for *F* sufficient force, as before, to produce equilibrium in the ap.

c. Calculate the ratio of velocity that would be gained if an unbalanced force acts at *F.*

d. Apply weights at *F* and *R,* and see if there be equilibrium when the ratio between them is the inverse of the ratio between their respective arms.

79.

Ap.: calipers, and ap., as shown in Fig. 30.

a. With calipers measure the diameters (inside the grooves) of the wheel, *B,* and the axle, *C,* and calculate what the ratio between the force and resistance, applied at their circumferences, must be, to produce equilibrium.

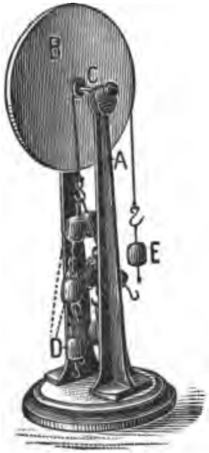

FIG. 30.

b. Wind cords about each and apply weights on opposite sides of their common axis and verify your calculation.

c. If the resistance is applied at the axle, what mechanical advantage will be gained?

d. When there is equilibrium between the force and resistance, is work done? Why? On what condition is work done?

e. Having produced equilibrium between *F* and *R,* with the hand pull down the cord wound on the axle, just sufficient to produce motion; do the same by pulling down the cord on the wheel. At which point are you obliged to exert the greater force to overcome friction?

f. Given the average resistance offered by friction, 1 oz. ($\frac{1}{16}$ lb.), how would you calculate the work wasted in moving the resistance a given distance when the force is applied at the circumference of the wheel and the resistance at the axle?

80.

Ap.: weighing-ap., and ap. as shown in Fig. 31.

a. Support the board, as shown in Fig. 31, so that the edge of the bevel of the supporting-block coincides with some one of the equal division marks on the edge of the board. Draw a horizontal line (as *MN*, Fig. 32), of indefinite length. From some point, *C*, in this line, on some convenient scale, erect a vertical line, *CA*, to represent the hight of the supporting-block. From *A* draw a line, *AB*, meeting *MN* and representing the distance, *AB*, on the board, and the slope or gradient of the inclined plane. Weigh the body, *D*, to be supported on this plane. From some point, *E*, in the line, *AB*, draw a vertical line, *EF*, to represent the magnitude and direction of the weight of *D*. From *F* draw *FG*, at right angles to *AB*, and complete the parallelogram, *EHFG*. The line, *EH*,

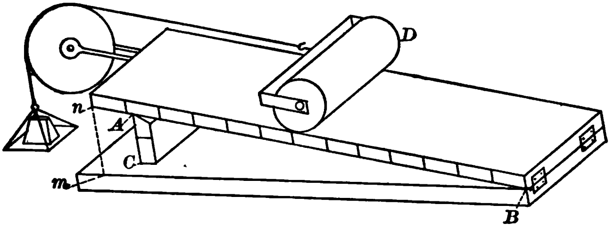

FIG. 31.

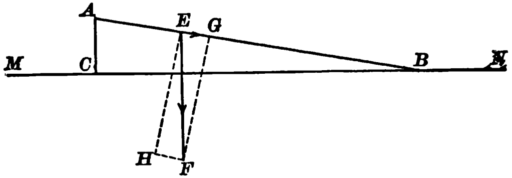

FIG. 32.

represents the component of the weight which is exerted upon the plane, and the line, *EG*, represents the component acting parallel with the plane, and, therefore, the magnitude of the force needed to support the body on the plane. Hence the force required $= W$ (weight) $\times \frac{GE}{FE}$, or (since the triangle, *EFG*, is similar to the triangle, *ACB*) $W \times \frac{CA}{BA}$.

b. Calculate the force required to support *D*, in accordance with the foregoing directions; weigh the pan, and place weights enough in the pan to make up, together with the pan, the required force, and verify your calculation.

c. The ratio 2 : 12 (*i.e.* a rise of two spaces in 12 spaces; see Fig. 31) is commonly called the *gradient* of the inclined plane. State how, knowing the gradient of a road and the weight of a vehicle, and disregarding friction, you can calculate the force required to support the vehicle on the road; *i.e.* to keep it from running down the road.

TRIBOMETRIC MEASUREMENTS.

81.

Ap.: same as above, with a sleigh or plank, about 6″ × 6″ × 2″, with eye-bolts so attached that cords passing from them over the pulley will be parallel with the plane; and a box of sand.

Weigh the sleigh, place it on the board near the end, opposite the pulley, with one of its large sides in contact, and the fibers of both parallel with one another; pass the cord over the pulley, and suspend the pan. Pour sand slowly into the pan until the sleigh begins to move. Weigh the pan and sand, and ascertain the *F* necessary to overcome the friction, which, of course, is an approximate measurement of the friction. The value of the fraction, $\frac{\text{friction}}{\text{pressure}}$, is called the *Coefficient of Friction, C; i.e.* $C = \frac{F}{P}$. Empty the pan, repeat the experiment at least three times, get the *C* in each case, and tabulate the results as follows: —

P.	*F.*	*C.*
. . .	. . .	. . .
. . .	. . .	. . .
. . .	. . .	. . .
	Average, . . .	Average, . . .

82.

Place a dish of sand on the sleigh, which weighs the same as the sleigh, so that the pressure may be exactly doubled. Repeat, and tabulate the results as in the last experiment. Compare the average coefficients obtained in these two experiments and determine whether *the friction between two surfaces is* (at least approximately) *proportional to the pressure between them.*

83.

Repeat Ex. 81, and as soon as the sleigh begins to move, see if by placing the hand beneath the pan you can diminish the force used to overcome the friction and still the sleigh continue to move, and determine whether *the sticking friction is greater than the slipping friction.*

84.

Place the sleigh on one of its narrow sides and attach the cord to the eye-bolt, near this side, so that the cord will be parallel with the plane, and ascertain by at least three trials the Av. C. Compare this Av. C. with the Av. C. obtained in Ex. 81, and determine whether, *when the pressure between two surfaces remains the same the friction is* (at least approximately) *independent of the area of contact.*

85.

Place the sleigh so that its fibers will be at right angles with those of the board; ascertain the Av. C., and determine whether *the friction between surfaces of wood is less when the fibers in the two surfaces are parallel.*

86.

Load the sleigh until its weight is equal to the weight of the cylindrical body (Fig. 31); ascertain the C for the sleigh and the cylinder; compare, and determine whether *rolling friction is much less than sliding friction, the pressure being the same.*

87.

Ap.: as in Fig. 31; also spring balance, graduated in ounces, and a yard-stick.

a. Weigh *D*; then place it on the inclined plane and connect it by the string with the hook of the spring balance. Keeping the string parallel with the plane, draw *D* up the plane *very slowly*, and find by several trials the *least* force necessary to keep it in motion. Compute (from the formula $W = FS$) the work (in inch-ounces) that would be done in moving *D* over the entire inclined plane.

b. When *D* is moved the entire length of the inclined plane, it is raised a vertical distance equal to *mn*. Suppose that *D* were suspended from the spring balance, and were raised vertically up the same distance, *mn*, how many inch-ounces of work would be done?

c. How does the work done in raising *D* a distance, *mn*, by the "aid" of the inclined plane, compare with the work done in raising the same body the same distance without the aid of any machine?

d. What is the nature of the *aid* received from the machine?

88.

Ap.: upright iron rod (like that accompanying the "desideratum ap."); clamp (same as used with ring-stand); pair of pliers; iron ball (about 1 in. diameter), pierced by a small hole through the center; tow-string or small flexible wire, about 8 ft. long; calipers, measuring-stick, and watch. The clamp being attached to the vertical rod at a suitable elevation grasps the pliers, which are placed vertically with the handles upward. The string and ball pendulum is suspended from the pliers, whose two bearings press the string.

Determine whether the vibrations of a pendulum are isochronous (of equal time); *in other words, whether the number of vibrations in a given time are equal, provided the amplitude of the vibrations are never very great.* Make a pendulum about 60^{cm} long. Count the number of vibrations made by it in one minute when swinging (1) through an arc of about 8^{cm}, (2) about 16^{cm}, (3) about 50^{cm}, and record the results and your conclusion.

89.

a. Find the relation between the length of a pendulum and its time of vibration. Take for the length of a pendulum the distance from the point of suspension (or axis of motion) to the ball, and add to this one-half of the diameter of the ball, measured with the calipers. Make pendulums (1) 25^{cm} long, (2) 50^{cm} long, (3) 1^{m} long, and (4) 2^{m} long. Ascertain and record as below: —

Length of Pendulum.	Time of 100 vibrations.	Time of one vibration.	$\sqrt{\text{Length}}$.	Time of one vib. $\times \sqrt{\text{length}}$.

b. Deduce the law of vibration of a pendulum supplying the following ellipsis: The time of vibration of a pendulum varies . . . . the length of the pendulum.

90.

a. Ascertain the value of g. If n be the number of double vibrations (*i.e.* back and forth) of a pendulum in a unit of time, whose length is l, and g represent the acceleration due to gravity, then it can be shown (see Maxwell's "Matter and Motion," Chap. VII.) that

$$g = 4\,\pi^2 n^2 l.$$

Take a pendulum (say) 45^{cm} long, ascertain the number of double vibrations made by it in (say) one minute, whence compute the number (n) per second in order that the value of g may be found for one second. Making substitutions in the above formula, find the value of g. It will be sufficiently accurate to let $\pi^2 = 10$.

b. What sources of error in your experiment have you not allowed for?

Example: Suppose that a pendulum 64^{cm} long makes 37 double vibrations in a minute; then $g = 4\,\pi^2 n^2 l = 4 \times 10 \times \frac{37^2}{60^2} \times 64 = 974^{cm} = 9.74^{m}$.

HEAT.

91.

Ap.: board on which are fastened wires of (1) iron, (2) copper, (3) brass, and (4) German silver (Fig. 33); and alcohol or Bunsen burner.

a. If you find the wires hot, cool them by thrusting the heated ends into water. Support the board in a horizontal position, and place a lamp flame where the wires meet, so that all the wires will have an equal opportunity to get heated. Place a finger on both the iron and copper wires, near the flame, retreating as the heat becomes unbearable. You will, in time, find that the points which you touch reach a stationary stage; *i.e.* these points lose heat as fast as they receive it.

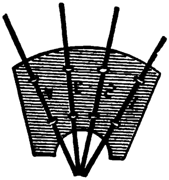

FIG. 33.

Find the relative distances of the bearable points of the several wires from their heated ends, and arrange the metals in the order of their conductivity, beginning with the best conductor. [The exact relative conductivity of these metals cannot be ascertained by comparing these lengths, as other things beside conductivity enter somewhat into the computation.]

b. In what way do points along the wires lose heat, so that they ultimately reach the stationary temperature?

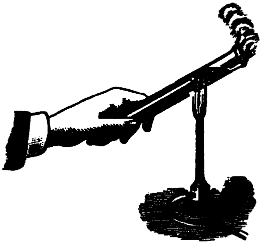

FIG. 34.

92.

Ap.: test-tube 6 in. long, and Bunsen burner or alcohol lamp.

Fill test-tube about four-fifths full of water, wipe dry the outside, grasp it with the fingers near the bottom, and, inclining it a little, hold it in the flame of the burner, but do not allow the flame to lap over the empty portion of the tube. Continue heating until the water boils, and note whether the water near the bottom gets hot. Is it practicable to make a body of liquid hot by applying heat at the top? Why?

93.

Ap.: test-tube 6 in. long and $\frac{3}{8}$ in. diameter, 4 oz. beaker, about 3 oz. of pulverized ammonium chloride, ice water, test-tube holder, and burner.

a. Take beaker about two-thirds full of ice-water, and test-tube with ice water to a depth of 1 in. Pour about $1\frac{1}{2}$ oz. of the powder into the beaker of water and stir it with the test-tube, holding both beaker and tube near their upper parts, so as not to communicate heat to the water in either from the hands. Pour in more powder from time to time, not waiting for all to dissolve, until the water in the tube is all frozen. Then fill the tube to within 1 in. of its top with ice water. Wipe the outside of the tube dry, not touching with the hand the part where the ice is; then grasp the tube with the holder, just above the ice, hold it obliquely so that the flame of the burner will envelop the tube a little below the surface of the water, and boil the water at the top without dislodging the ice (by melting) from the bottom.

What does this experiment show with reference to the conductivity of water?

b. Suppose the flame and ice to exchange places, end for end: can you boil the water without melting the ice? Why?

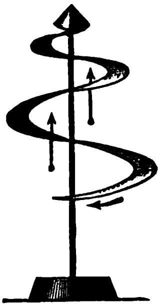

FIG. 35.

94.

Ap.: wire 18 in. long, bent at a right angle 7 in. from one end, the end nearest the bend being filed down to a sharp point; a spiral strip of paper (Fig. 35) cut from glazed paper (better asbestos paper), $\frac{3}{4}$ in. in width, the spiral when suspended not exceeding 6 in. in length.

a. Place the spiral, supported on the point of the wire, over a hot stove or lamp flame.

Explain the phenomenon that occurs.

b. State all the transformations and transferences of energy which occur during the experiment.

95.

Ap.: kerosene lamp, touch-paper, and spiral, as in last experiment.

a. Light the lamp and note the appearance of the flame. Then gradually bring the chimney down around the flame and note the changes in the flame.

b. When the chimney is nearly down to its support, ignite a piece of touch-paper and hold the smoking part near the lower end of the chimney; note any evidence of a draft, and explain how it is caused.

c. Hold the spiral over the flame when the chimney is in position and when it is removed; note any difference in the results, explain the difference, and explain the change in the character of the flame which the chimney causes.

96.

a. Open a door separating a warm room from a cold one. Hold a candle flame near the bottom of the passage-way and raise it gradually to the top, observing whether it exhibits any evidence of a current of air between the rooms.

In what direction is the current at the bottom? at the top? What about currents midway?

b. Why should there be currents in opposite directions?

97.

Ap.: glass tube with bulb blown at one end, the other end dipping into a beaker of water colored with a few drops of ink or of a solution of permanganate of manganese.

Grasp the bulb with the palm of the hand, note what occurs; remove the hand in about a minute, note again what occurs, and explain every phenomenon which has occurred.

98.

Ap.: Wolpert's air-tester, bottle of clear lime-water (saturated solution), wooden stand, test-tube cleaner, and a bottle of vinegar.

a. Ascertain (approximately) *the number of parts in 10,000 of carbonic acid gas (and thereby determine approximately the degree of pollution by respiration and combustion) in the air of the laboratory* (or other room).

Clean the test-tube with water containing a little vinegar, and afterwards rinse thoroughly with clean water. Fill the *clean* test-tube even with the horizontal mark. Expel all the air possible from the bulb, *A* (Fig. 36), by pressing on it with the thumb; then allow it to fill with air of the room. Insert the small glass tube, *B*, into the lime-water nearly to (almost touching) the bottom. Expel the air in the bulb again with moderate rapidity, so that the bubbles may rise nearly to the top of the tube, *C*, but do not allow the liquid to overflow. Continue the pressure until you have withdrawn the tube from the liquid, when you will allow the bulb to refill with air of the room. At the end of each expulsion place the bottom of the test-tube on a sheet of white paper in good daylight, and look vertically down through the liquid at the black mark on the bottom of the test-tube; repeat the process, being careful not to affect the result more than necessary with your own breath, until the turbidity of the lime-water renders the mark invisible. "If the mark becomes obscured after filling the bulb ten or fifteen times only, the air of the apartment is unfit for continuous respiration. With good air it must be filled twenty-five times and upwards. The normal amount in pure out-door air is 3 to 5 parts per 10,000."

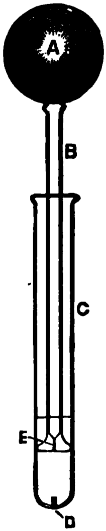

FIG. 36.

Ascertain, by comparing your results with those given by Prof. Wolpert in the table below, the number of parts of carbonic acid in 10,000 of the air of your room.

Number of Fillings.	Carbonic Acid per 10,000.	Number of Fillings.	Carbonic Acid per 10,000.	Number of Fillings.	Carbonic Acid per 10,000.	Number of Fillings.	Carbonic Acid per 10,000.
1	200.	16	12.5	31	6.4	46	4.3
2	100.	17	12.	32	6.3	47	4.2
3	67.	18	11.	33	6.1	48	4.1
4	50.	19	10.5	34	5.9	49	4.1
5	40.	20	10.	35	5.7	50	4.0
6	33.	21	9.5	36	5.5	51	3.9
7	29.	22	9.1	37	5.4	52	3.9
8	25.	23	8.7	38	5.3	53	3.8
9	22.	24	8.3	39	5.1	54	3.7
10	20.	25	8.	40	5.	55	3.7
11	18.	26	7.7	41	4.9	56	3.6
12	16.	27	7.4	42	4.8	57	3.5
13	15.	28	7.1	43	4.6	58	3.5
14	14.	29	6.9	44	4.5	59	3.4
15	13.	30	6.6	45	4.4	60	3.3

b. Comment on the condition of the air in your room.

99.

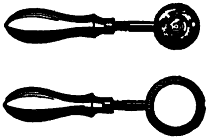

FIG. 37.

Ap.: ring and ball, and heating ap.

See if the ball will pass through the ring, then devise, perform, and describe some treatment which will show (1) the expansibility of metal on a rise of temperature, and (2) the contraction of the same on a reduction of temperature.

100.

Ap.: 4 oz. flask; stopper for same, through which passes a glass tube and thermometer; glass (Bunsen battery) jar, ice chips, and table salt.

Find the temperature of water at its maximum density. Fill the flask with water at a temperature not lower than 10° C. Stopper it tightly, leaving the water standing about 2 or 3 in. in the tube, above the stopper. Nearly fill the jar with a freezing mixture of ice and salt (about 5 parts by volume of the former to 1 of the latter). Cover the flask with the mixture, leaving only the top of the flask exposed. Note the changes in volume of the water, as indicated by the water in the tube. Observe the temperature of the water when its volume is least.

101.

Ap.: flask having side tube, chemical thermometer, heating ap., and barometer.

Test the boiling-point of a thermometer. Take flask quarter full of water, close the mouth with a stopper pierced with the thermometer. It is desirable that the boiling-point on the thermometer stem should be not more than 5° above the stopper, and the bulb should be about 2 in. above the water, so that the water by ebullition will not reach it. Boil the water, and note the highest attainable ascent of the mercury in the thermometer, viewing at a right angle with the column, and dividing with the eye each division on the stem into tenths. Consult the barometer and allow 1° C. for 27^{mm} excess or deficiency in the hight of the barometer column, the temperature of 100° C. being defined as that of steam from water boiling under a pressure of 760^{mm}. *State what error, if any, you discover in the boiling-point of the thermometer.*

102.

Ap.: chemical thermometer.

Wash the bulb of the thermometer, place it under the tongue as far back as possible, close the mouth, and breathe through your nostrils. At the expiration of about 90 seconds, let another person read the temperature of the body while the thermometer bulb is in the mouth.

103.

Ap.: barometer, two heating ap.; two tall beakers, one containing distilled water, the other a concentrated solution of saltpetre. Both liquids are boiling briskly, and thermometers are suspended so that the bulb of each is submerged, but not nearer the bottom of the beaker than 2 in.

a. If the liquid in either beaker does not cover the bulb at least 2 in., pour some water into the beaker and wait until it boils strongly. Note the boiling-point of each.

b. After several minutes observe again the boiling-point of each. If there is any change, try to account for it.

c. If the boiling-point of the water is higher or lower than 100° C., consult the barometer and account for the discrepancy.

d. Assuming the standard pressure to be 760^{mm}, calculate the number of millimeters pressure corresponding to a change of 1° in the boiling-point.

104.

Ap.: test-tube and cork to fit, test-tube holder, tumbler of water, and burner.

Take test-tube half full of water and boil it. Remove from the flame and quickly cork it. Invert, and dip its mouth beneath the water in the glass, withdraw the cork, and pour water upon the top (bottom) of the tube. Note and explain phenomena.

105.

Ap.: as shown in Fig. 38.

a. Place the test-tube half full of ether in a beaker containing water at about 60° C. Introduce the thermometer into the ether, not allowing it to touch the test-tube, and ascertain the boiling-point of ether. *Caution: do not allow the flame to come near the vapor of ether.*

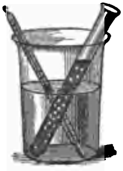

FIG. 38.

b. Disregarding the combustibility of ether, what difficulty would you encounter in attempting to get the boiling-point by applying the flame of a burner directly to the test-tube?

106.

Ap.: hydrometer, hydrometer jar or long test-tube, thermometer, and ap. for distillation.

Rectification by fractional distillation. Dilute (say) 150^{cc} of alcohol with an equal volume of water, test the specific gravity of the mixture with the hydrometer, and pour it into the flask of the distilling ap. Through the stopper of the flask pass the thermometer. Distil half over, noting the temperature of the steam from time to time. Find the specific gravity of the distillate.

State the principle involved in fractional distillation. [*Dry distillation* is a term applied to distillation of solids; *e.g.* the purification of zinc. When the temperature is raised high enough to decompose the substance and evolve new products, the process is called *destructive distillation; e.g.* distillation of wood in close vessels. See Williams's "Chemistry," p. 180.]

107.

Ap.: thermometer, nickel-plated lemonade shaker (which we call a *calorimeter*), glass beaker with indented lip, hygrometer.

Pour water at a temperature (say) about 5° below that of the room into the calorimeter to the depth of about 3^{cm}. Place the bulb of the thermometer in the water and do not remove it from the water throughout the experiment. Very gradually reduce the temperature of the water in the calorimeter by stirring into it ice-water from the beaker till you discover a slight dimness on the portion of the outside next the water. [Caution: Direct your breath away from the apparatus throughout your observations, so that the moisture of your breath may not change the condition of the air in the vicinity of the calorimeter.] Pour some of the water out from the calorimeter from time to time, so as to enable you to reduce the temperature of its contents lower.

Note the temp. of the water when the first dimness appears, also when it disappears. Take the mean of the two temp. for the dew-point. Record as follows:

Temp. at which dew appears . . . .
" " " " disappears . . . .
Average temp. . . . .
Humidity of air in laboratory
as indicated by the hygrometer (expressed as a %) . . . .

108.

Ap.: as shown in Fig. 39; heating appliances and additional tumbler of cold water.

Boil the water in the test-tube for about five minutes, then remove the heat, leave the end of the tube in the tumbler of cold water, introduce the test-tube into the other tumbler of cold water, and allow the water of the test-tube to cool for some time. Observe carefully, and explain every phenomenon that occurs from the time when you first apply heat to the end of the experiment.

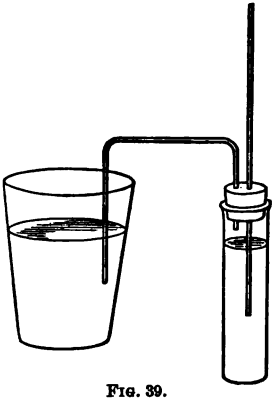

FIG. 39.

109.

Ap.: chemical thermometer supported by a ring-stand and clamp in a window draft; small atomizer filled with ether.

Notice the temperature indicated by the thermometer, then blow a spray continuously upon the bulb of the thermometer as long as any change in temperature is observable. Note the lowest temperature attainable and give the philosophy of this method of reducing temperature.

110.

Ap.: similar to that shown in Fig. 40; thermometer, balance, and weights.

Find the latent heat of steam. Find the weight of the dry beaker, w_1, in decimal of a kilo. Fill it half full of water. Find the weight of the water, w_2. Take the flask about two-thirds full of water, stopper it, and heat it over a three-tubed burner. Meantime get the temperature of the water, T_1, in the beaker, which should be near the temperature of the room. As soon as the water of the flask boils fast and has driven out water which may have condensed in the tube, insert the free end of the tube in the water in the beaker, noting the time by the clock when you insert it. At the end of ten or fifteen minutes withdraw the tube, stir well the water in the beaker with the thermometer, and get its temperature, T_2. After observing the temperature, wait for one minute and observe the fall of temperature during this time in consequence of loss of heat by radiation. At first, when the water had the temperature of the room, there was no loss by radiation; hence the average rate of cooling per minute is $\frac{0^\circ + a^\circ}{2}$, a° being the maximum rate of cooling as observed. So that if the experiment lasted ten minutes, the loss by radiation may be reckoned as $\frac{0^\circ + a^\circ}{2} \times 10\ (= b^\circ)$. The corrected value of the temperature of the water in the beaker at the end is therefore $T_2 + b^\circ\ (= T_3)$.

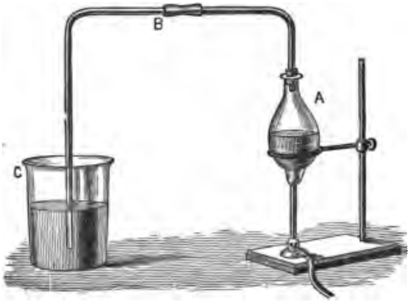

FIG. 40.

Get the weight of the beaker and contents, w_3, and determine the weight of the condensed steam, w_4: $w_4 = w_3 - (w_1 + w_2)$. Now $w_4{}^k$ of steam at 100 C. becomes $w_4{}^k$ of water at 100° C., which mixes with $w_2{}^k$ of water at T_1, raising its temperature to T_3 and itself falling $100 - T_3°$. But a certain quantity of water in falling $100 - T_3°$ could raise an equal quantity of water only an equal number of degrees; hence the balance of the heat required to raise the $w_2{}^k$ of water from T_1 to T_3 must arise from the latent heat of the steam which is represented by

$$x = (w_2 + w_1 \times 0.2) \times (T_3 - T_1) - w_4 (100 - T_3),$$

in which $w_1 \times 0.2$ represents the heat given to the beaker, 0.2 being the specific heat of glass. $\frac{x}{w_4} =$ number of calories of latent heat in 1^k of steam.

111.

Ap.: iron ball, basin of water, chemical thermometer, burners, glass jar (*e.g.* Bunsen battery jar), balance and metric weights, vessel of water at the temperature of the air as nearly as convenient.

Find the specific heat of iron. Weigh the ball. Weigh the jar Take water in the jar of sufficient depth to completely cover the ball. Weigh the water taken. Suspend the ball by a string from some convenient support in the water boiling in the basin, so as to be completely submerged, but not to touch the basin. Let the ball remain in the boiling water five minutes. Meantime take the temperature of the boiling water and afterwards of the water in the jar, moving the thermometer about in the water as you do it, so that the heat of the thermometer taken from the hot water may be equally distributed in the water. Quickly wipe the ball with a dry cloth and lower it into the jar of water, keeping it covered and moving it about with the string for five minutes, or long enough for the ball and water to acquire a uniform temperature. Find this temperature.

Let w_1 be the weight of jar; w_2, the weight of water; w_3, the weight of ball. Let T_1 be the temperature of the jar and water; T_2, the temperature of the ball when taken from the hot water; T_3, the resulting temperature. The specific heat of glass is about 0.2; hence the heat required to raise the temperature of the jar is two-tenths of that required to raise the temperature of an equal weight of water. This equivalent may therefore be represented as $w_1 \times 0.2$. Then the specific heat of iron

$$= \frac{w_2 + w_1 \times 0.2}{w_3} \times \frac{T_3 - T_1}{T_2 - T_3}.$$

State all sources of error that occur to you.

112.

Ap.: as in Ex. 111.

Find the temperature of the iron ball when raised apparently to the temperature of the flame, and thereby ascertain approximately the temperature of the flame. Get weight of jar (w_1), weight of water (w_2), and weight of ball (w_3), as in Ex. 111. Suspend the ball by a small platinum wire, and cover it with flames from several lamps of the same kind, and heat as hot as possible; then plunge it quickly into the water, being careful not to let it touch the jar. Move it about until the temperature of the two is constant, and find this temperature (T_2). Let T_1 be the original temperature of the water, and x the temperature (sought) of the flame. Then 0.11 (specific heat of iron) $= \frac{w_2 + w_1 \times 0.2}{w_3} \times \frac{T_2 - T_1}{x - T_2}$. Thence deduce $x°$.

State sources of error.

113.

Ap.: same as in Ex. 111.

Find the quantity of heat rendered latent in melting 1^k of ice. Weigh in kilograms the dry jar. Wipe dry some pieces of broken ice and put in the jar and quickly weigh. Take about twice its weight of hot water, in which is a thermometer showing its temperature; pour it upon the ice and stir with the thermometer. Note the temperature when all the ice is melted. Drain, and remove the thermometer, and weigh the jar and contents, and deduce the weight of hot water added.

Let w_1 be the weight of the jar: w_2, the weight of the ice; and w_3, the weight of hot water. Let T_1 be the temperature, in centigrade degrees, of the hot water; T_2, the temperature of the water when the ice is melted; and assume that the temperature of the ice is $0°$. The specific heat of glass is 0.2.

View the question as follows: w_3^k of water have sunk from T_1 to T_2, or through $T_1 - T_2°$. Therefore $w_3\ (T_1 - T_2)$ calories have been given out. These have melted w_2 of ice, and heated w_2 of ice-cold water, and w_1 of ice-cold glass, from $0°$ to T_2; in doing the latter (*i.e.* raising the temperature of water and glass) they have employed $(w_2 + w_1 \times 0.2)\ T_2$ calories. All the rest of the heat, namely, $w_3\ (T_1 - T_2) - (w_2 + w_1 \times 0.2)\ T_2$ calories have been employed in simply melting the w_2 of ice. Hence the number of calories consumed or rendered latent in melting 1^k of ice $= \dfrac{w_3\ (T_1 - T_2) - (w_2 + w_1 \times 0.2)\ T_2}{w_2}$

114.

Ap.: model of a steam engine (Fig. 41), showing movement of slide valve. and reversal of steam by means of link motion.

a. Set the engine in such a position that steam would enter the cylinder on one side of the piston and leave it on the other. Make a sectional drawing of the steam chest, cylinder, piston, piston rod, and valve rod. Represent by arrows the direction in which the steam is moving at that instant in every compartment; also the direction in which every moving part is moving.

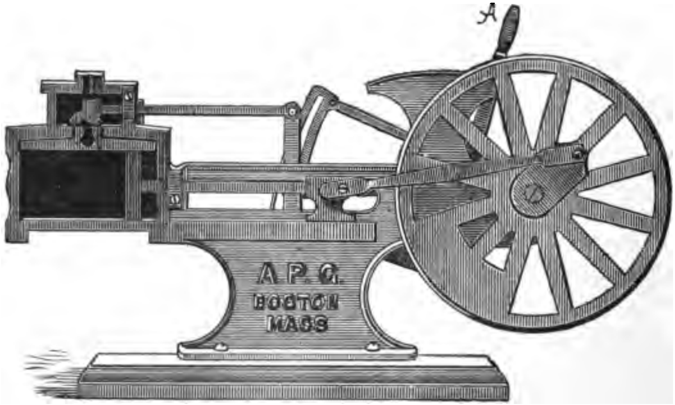

FIG. 41.

b. Move the parts so as to represent an exact reversal of all the above movements. Make a drawing to correspond to this new condition of things.

c. Place the parts so as to represent the position at the instant that the "cut off" occurs, representing accurately the position of the piston and the valve at that instant.

d. Move the lever, *A*, from side to side; discover and describe the method by which the so-called link motion reverses the steam.

ELECTRICITY.

115.

Ap.: tumbler of water acidulated with about one-twentieth its volume of sulphuric acid; strip of copper and two strips of zinc (one amalgamated), with copper wires attached to each; double connectors.

a. Put the copper strip into the liquid. State what, if any, phenomena occur, especially whether there is any trace of chemical action observable.

b. Place the unamalgamated zinc in the liquid, but do not allow it to touch the copper strip. State what, if any, phenomena occur.

c. Join the wires of the two strips with a double connector, look carefully for any change, and state what it is.

d. Remove the zinc strip, wait until the liquid becomes clear, then introduce the amalgamated zinc. Does there appear to be any chemical action? If so, seek for a strip so well amalgamated that it will show no action later than about one minute after it is put into the liquid. Does amalgamation protect the zinc from chemical action?

e. Connect the zinc with the copper as before. Is there any appearance of chemical action now? If so, on which strip? Is the copper really acted on in any of these cases?

116.

Ap.: Bunsen quart cell, magnetic needle, and connector.

a. Place the needle near the cell; let it come to rest; join the leading-out wires; grasp the connecting wire with your two hands a little farther apart than the length of the needle; bring the portion of wire between your hands down over and very near to the needle, and hold it for a few seconds in the same position (*i.e.* north and south) that the needle had before it was approached by the wire. Is the needle affected by it? Does it take a new position?

b. Is there evidence of an action between the wire and the needle when they do not touch each other? If there is an action, what is the name of the force that acts? [Do not call it electricity; for electricity is not a force.]

c. Place the wire in the same relative position as before; remove one of the wires from the connector, *i.e.* break the circuit; what happens?

d. When the circuit is closed, is there evidence that the wire possesses energy? What name will you give it? [Do not call it electricity; electricity is not energy.]

117.

Ap.: as above, and pieces of wood, glass, hard rubber, iron, zinc, lead, small dish of mercury, etc.

Place a section of wire over the needle, as before, and close the circuit by introducing pieces of each of the substances given you between the leading-out wires, pressing the latter firmly against each body, except the mercury, into which you need only to dip the ends of the wires. Divide the substances into two classes; viz. good conductors and poor conductors, as determined by the action upon the needle when each is in the circuit.

118.

Determine which end of the needle is N-seeking. Hold a section of wire over the needle, as in Ex. 116; ascertain by Ampère's rule whether the current flows northward or southward through this section, and thereby *determine which of the two elements* (*e.g.* zinc or carbon) *of your cell is electro-positive.* [You are simply to imagine yourself swimming in the current in this section of the wire, looking down upon the needle below (Fig. 42), and determine whether you must be swimming northward or southward in order to find the N-seeking pole "deflected toward your left," for in this case you will be swimming "*with* the current."]

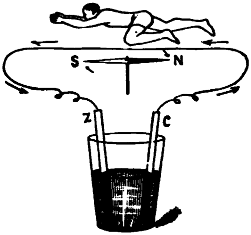

FIG. 42.

119.

a. Having decided which element of your cell is electro-positive in accordance with Ampère's rule, proceed to *verify the rule.*

Place a section of wire so that the current will flow *northward* over the needle, and see whether the needle is deflected to an imaginary swimmer's left on the conditions given in the rule.

b. Carry the wire below the needle, and verify.

c. Reverse the direction of the current by reversing the section of wire between the two hands, and verify.

d. Raise the wire above the needle, and verify.

e. What two ways of reversing a deflection have you discovered?

General directions for using a galvanometer. The galvanometer should be placed near the edge of the table where you stand; other apparatus connected therewith must give place to this. Short, flexible wires should be inserted in the screw-cups of the galvanometer and should not be removed while experimenting.

Set the galvanometer; *i.e.* rotate it slowly and carefully until the needle points exactly to zero at each extremity. To accomplish this, the instrument must be levelled by means of the levelling screws beneath the galvanometer. If the needle when set does not seem to lie in the magnetic meridian (*i.e.* point due north and south), it is probable that there is a torsion in the silk fibre. Seek assistance or advice from the teacher. Care must be exercised that no article containing iron or steel is located near the galvanometer.

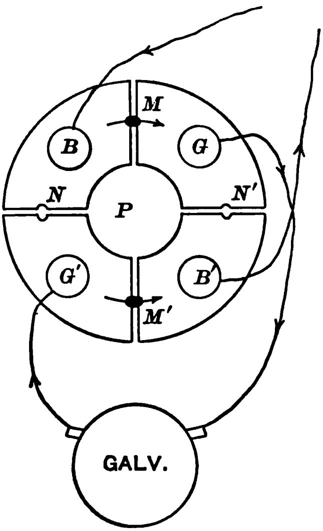

FIG. 43.

In taking observations on the galvanometer there are three errors which must be especially guarded against, viz.: (1) Error of parallax; *i.e.* apparent displacement of the needle, due to looking obliquely down upon it. The observer should look vertically down upon the needle. (2) Error of eccentricity; *i.e.* error due to fault in centering the needle. To correct this, readings at both extremities of the needle should be made and the *mean* of the two readings should be used. (3) Error of parallelism; *i.e.* error arising from any departure from parallelism between the needle and the coils of the galvanometer. To correct this the current should be reversed through the galvanometer and a second set of readings made,

and the mean between the two should be taken. For this purpose a pole-changer should be used. This is an instrument by which the current may be reversed, at will, through any portion of the circuit, or through any instrument in the circuit. *P* (Fig. 43) represents a pole-changer introduced into a circuit in such a manner that the current can be sent, at will, either way through the galvanometer (Galv.). The circuit being opened at any suitable point, the two electrodes are introduced into the two screw-cups, *B* and *B'*. Wires are then led from the screw-cups, *G* and *G'*, to the galvanometer.

Now if the two holes, *M* and *M'*, are plugged (with brass plugs), the circuit will be closed, and the current will flow as shown by the several arrow-heads. To reverse the current through the galvanometer, remove the plugs from *M* and *M'*, and insert them into the holes *N* and *N'*, pressing them firmly in their places.

The sensitiveness of a galvanometer can be greatly increased by reducing, by a *neutralizing magnet*, the intensity of the magnetic field about the needle. A bar-magnet is placed so that its axis shall be in the same vertical plane with the axis of the needle, but the adjacent poles should be of the same sign. The resultant magnetic field will be the difference of the two fields, and by varying the distance of the magnet, this difference may be made as small as desired, and the sensitiveness increases with the diminution of the intensity of the field.

The reverse of this process is also sometimes useful; *i.e.* increasing the intensity of the field, and thus diminishing the sensitiveness of the galvanometer when too sensitive for a given purpose. This is accomplished by placing magnetic poles of opposite sign adjacent to each other, and regulating the intensity to suit your purpose by adjusting the distance between the poles of the two magnets.

The blank pages opposite these directions may be utilized in recording the results of original investigations, or work dictated by the teacher, in connection with the use of a galvanometer.

120.

Ap.: rheostat, set of spools of wire (of different metals, sizes, and lengths), galvanometer with tangent needle, Bunsen or Daniell cell, and metric micrometer calipers.

Measuring resistances by the "substitution" or "balancing" process.

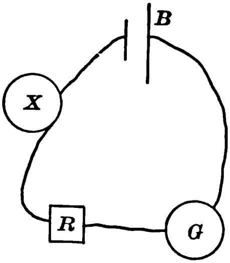

FIG. 44.

First place a switch of the rheostat on the brass stud marked 2 (ohms), and the other two switches on the studs marked 0. Then *set* the galvanometer (see directions above), and join in circuit, as in Fig. 44, the battery, *B*, the galvanometer, *G*, the rheostat, *R*, and the spool, *X*, marked 1, the resistance of whose wire is required. (The wire on any spool is introduced into circuit by inserting the electrodes into the cups each side of the spool.) Reduce the deflection of the galvanometer needle to about 45° by throwing resistance into *R*.

[Caution: Throughout the experiments, never allow the circuit to be closed, even for an instant, unless the total resistance of the circuit is greater than that of *X*, since this would materially affect the E.M.F. of the battery and thereby introduce an error into your work.]

Read the deflection at one end of the needle, estimating with the eye to half a degree. Note the resistance in the rheostat and call it R_1. Remove X from the circuit, increase the resistance in R, so as to avoid closing the circuit through too small a resistance. Close the circuit and change the resistance in R until the same end of the needle, deflected in the same direction as before, gives precisely the same deflection. Note the resistance now in the rheostat and call it R_2.

Now, inasmuch as the E.M.F. is supposed to be the same as before, and the needle shows that there is the same current flowing, it follows that there must be the same resistance in the two cases. The only change that has been made is in taking out X and putting more resistance into the rheostat: the amount put in must be just equal to that of X, which was taken out. Hence $R_2 - R_1 = X$.

121.

a. Measure the resistances of the wire on each of the other spools in the same manner; measure with the calipers the diameter of naked pieces of the two sizes of wire used, and tabulate the results as follows: —

No. of Spool.	No. of wire, Am. G.	Diameter of wire.	Length.	Kind of wire.	Resistance by substitution.
1	23	..	32 yds.	Copper	..
2	30	..	" "	"	..
3	23	..	16 "	"	..
4	30	..	" "	"	..
5	30	..	" "	G. Silver	..

b. Compare the resistances of spools 1 and 3 and account for the difference in their resistances.

c. Compare the resistances of spools 1 and 2 and state your inference. Do their resistances vary as the diameters, or as the squares of the diameters of the wires?

d. Compare the resistances of spools 4 and 5 and state your inference.

122.

Ap.: Wheatstone bridge, spools of wire, rheostat, galvanometer with astatic needle, and voltaic cell.

Measure resistances by use of the bridge. Carry the leading-out wires of the cell to the screw-cups, *BB'* (Figs. 45 and 46); introduce the rheostat at *RR*, the unknown resistance (*e.g.* spool of wire) at *xx*, and the galvanometer into the bridge at *GG*.

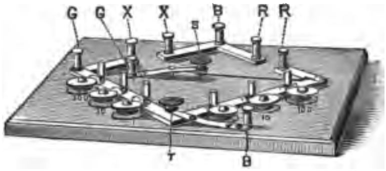

Fig. 5

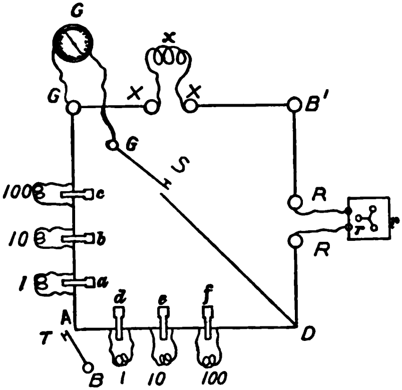

Fig. 46.

The pupil in his first attempts to use the bridge should seek personal assistance of the instructor.

Set the galvanometer so that the needle points to zero. Unplug 100 ohms in each branch (the other coils being all firmly plugged). Close the circuit at *T*, then the bridge at *S*, and observe in what direction the needle is deflected when the switches of the rheostat are all on the zero studs. Next throw (say) 50 ohms (a resistance probably larger than the resistance to be measured) into the rheostat, close at T and S again, and notice the direction of the deflection. If the two deflections are in different directions, you infer that any subsequent deflection like the first, will indicate too little resistance in the rheostat, and any deflection like the last will indicate too great resistance in the rheostat. Now regulate the resistance in the

rheostat so that on closing the bridge there will be no deflection of the needle. The resistance then in the rheostat is approximately the resistance sought. If this resistance is small, plug the 100's and unplug the 10's, and again regulate the resistance, if necessary, so that there will be no deflection. It will be well to repeat the process, making the resistances employed in the two branches of the bridge unequal, to see if the sensitiveness of the galvanometer is increased thereby, for the correctness of the results obtained with the bridge depends almost wholly upon the sensitiveness of the galvanometer. For example, let M (the resistance between A and D, Fig. 46) $= 100$, and N (the resistance between A and G) $= 10$; then when points G and G' have the same potential,

$$M : r \text{ (resistance in rheostat)} :: N : x.$$

123.

Ap.: battery, bridge, rheostat, galvanometer, 1 yd. of No. 30 platinum wire made into a coil; also a coil of German silver wire of same length and size; beaker of water at 15° C., another at (about) 100° C., and a thermometer.

a. Introduce the platinum wire into the cooler water and measure its resistance; then introduce it into the hot water and measure its resistance.

b. Substitute the German silver wire for the platinum and repeat all the above.

c. The correction for temperature (within a range of 0° to 100° C.) of all pure metals is about 0.004 the resistance at 15° C. (60° F.) for each degree Centigrade; for German silver (an alloy), it is about 0.0004, or, more accurately, about one-ninth as great. Calculate the corrections from the data obtained by yourself.

124.

Ap.: Bunsen, Daniell, or other cell, whose resistance is required; tangent galvanometer, pole-changer, and rheostat.

To measure the resistance of a battery. Join in circuit the battery, rheostat, pole-changer, and galvanometer (see Fig. 43). Throw resistance in or out until the deflection is between 55° and 60°. Keep the circuit closed for at least five minutes. Read with great care the deflection at the expiration of this time at both ends of the needle, estimating with the eye fractions of a degree. Reverse the current, take two more readings, and find the average of the four readings and denote it by a_1. Note also the resistance, R_1, of the rheostat at the time.

Increase the rheostat resistance until the deflection is between 30° and 35°. Read both ends, reverse, read again, and call the average of the four readings a_2, and the rheostat readings R_2. Then

$$X = \frac{R_2 \tan a_2 - R_1 \tan a_1}{\tan a_1 - \tan a_2},$$

X being the total resistance in the circuit outside of the rheostat. This is composed of battery resistance, galvanometer resistance, resistance of the connecting wires, etc. Considering the last negligible (especially if short, thick copper wires are used), and denoting the galvanometer resistance by g, the battery resistance, B, will be

$$B = X - g.$$

This value of B is, really, Battery + all resistances not otherwise accounted for.

[In future all galvanometers furnished by the author will have their resistances marked on them.

The resistance of a cell will vary with size, time since set up, length of use, the liquids used, and *very largely on the condition of the porous cup.* In a Daniell cell, new and freshly set up with zinc sulphate solution, the porous cup frequently has a resistance of many ohms. But if set up with dilute H_2SO_4, the cup resistance is much less. New cups may be soaked advantageously for a few hours in dilute sulphuric acid.]

125.

Ap.: Bunsen cell, galvanometer with tangent needle, rheostat, and pole-changer.

Test the galvanometer for the law of tangents. Join in circuit the battery (B), rheostat (R), pole-changer (P), and galvanometer (G), as in Fig. 47. Throw resistance into R such as to cause a deflection of about 25°; then of 30°, 40°, 50°, 60°, and 65°. Read both ends of the needle, and reverse the current at each place. Represent the respective mean deflections by a_1, a_2, etc., and the corresponding resistances in the rheostat by R_1, R_2, etc.

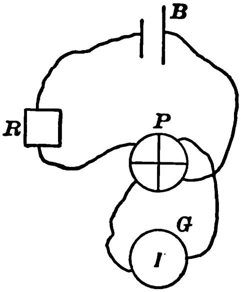

Fig. 47.

On the opposite page draw a square of 8^{cm} edge. Divide each edge into centimeters, and divide the square, by parallel lines, into squares (64), each of 1^{cm} edge.

Plot with R_1, R_2, etc., as horizontal distances (abscissas), and $\frac{1}{\tan a_1}$, $\frac{1}{\tan a_2}$, etc., as vertical distances (ordinates). The conformity of the galvanometer to the law of tangents is determined by the approximation of a line drawn through the points, which you have located, to a straight line.

[The pupil must receive previous instruction in plotting from the teacher, or from the study of some text-book which contains instructions thereon; *e.g.* the author's "Physical Technics," p. 1.]

126.

Ap.: Daniell cell, galvanometer and pole-changer, and rheostat.

Directions for the use and care of a Daniell cell. It is of the utmost importance that this cell be kept in a clean and proper condition. The zinc should be kept thoroughly amalgamated and clean. The copper plate should be often cleaned; likewise the porous cup should be kept free from deposits of copper. The parts above the liquid line should be paraffined to prevent salts from climbing up thereon. The cell should be closed through a resistance of about 10 ohms for at least fifteen minutes before it is used as a standard. The copper element should be kept in a concentrated solution of copper sulphate, and lumps of the same should be kept in the basket. Inside the porous cup, water, acidulated with sulphuric acid (specific gravity about 1.04; by volume, 50 to 1; by weight, 12 to 1), surrounds the zinc rod. The zinc must not touch the porous cup, and the cell should be disturbed as little as possible.

To obtain the "reducing factor" of a tangent galvanometer; i.e. a number by which, if the tangent of a deflection is multiplied, the product is the strength of the given current in ampères.

Join in circuit with the galvanometer a Daniell cell, rheostat, and pole-changer, so connected as to permit a reversal of current through the galvanometer. Regulate the resistance in the rheostat so as to obtain a deflection anywhere between 30° and 60° (45° is preferable). Keep the circuit closed fifteen minutes. Then read, with the greatest accuracy possible, both ends of the needle. Reverse the current and read both ends again. Represent the mean of the four deflections by a. Note the resistance in the rheostat and denote it by R, the resistance of the galvanometer by g, that of the Daniell cell, *as found at the time*, by B. Let E represent the E.M.F. of the cell. Then by Ohm's law

$$C = \frac{E}{R + g + B}.$$

Also, as the galvanometer follows the law of tangents (see Ex. 125),

$$C = k \tan a,$$

where k is the "factor" of the galvanometer. Hence

$$k \tan a = \frac{E}{R+g+B}$$

and $$k = \frac{E}{R+g+B} \cdot \frac{1}{\tan a}.$$

Substitute for E its value, 1.07 volts, and also, for R, g, B, and $\tan a$, their numerical values, and compute k. This factor is constant so long as the distance of the needle from the coils and the magnetic field of the needle are unchanged.

If, now, a deflection of (say) 57.5° happens to be produced, we know that the current producing it is $k \times \tan 57.5°$ ampères.

127.

Ap.: battery cell, whose E.M.F. is required; rheostat, galvanometer and pole-changer.

To find the E.M.F. of a battery. First method. Having obtained k, as in Ex. 126, proceed as follows, without disturbing the galvanometer. [If the needle is raised or lowered, the value of k will be changed.] Join in circuit the cell to be measured, the rheostat (throwing into it 100 ohms before closing the circuit), and the galvanometer and pole-changer. Throw out resistance gradually (avoid short-circuiting, as it may change the E.M.F. temporarily) until a deflection, anywhere from 30° to 60° (the larger deflections are generally preferable). Read both ends and the reversals, and call the mean deflection a. Note the resistance in the rheostat and call it R; that of the galvanometer g, and that of the battery B, and assume that the resistance of the connecting wires is zero.

The current at the time was $C = k \tan a$. Compute this. Then by Ohm's law

$$C = \frac{E}{R+g+B}, \text{ or } E = C\,(R+g+B).$$

Substitute in the latter the known values of C, R, g, and B, and compute E. [The value of B must be found *at the time* by the method of Ex. 124.]

128.

Ap.: as in last experiment; an additional rheostat, Daniell cell, and two connectors (preferably triple).

Second method. Connect as in diagram (Fig. 48). Let E_1 be the battery to be measured, and E_2 the Daniell cell, carefully set up. R_2 is a rheostat, and R_1 is the other rheostat, having in it a known resistance of at least 20 ohms. Adjust R_2 until the galvanoscope (with astatic needle), G, gives no deflection. Then

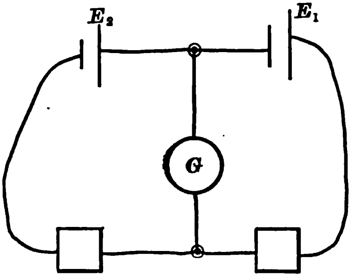

FIG. 48.

$$\frac{E_2}{E_1}=\frac{R_2+B_2}{R_1+B_1},$$

where B_2 and B_1 are the resistances of the two batteries, E_2 and E_1, respectively, *determined at the time*, as in Ex. 124, and E_2 and E_1 represent the E.M.F. of the respective batteries. If the resistances R_2 and R_1 are made so large that the resistances of B_2 and B_1 are not more than one per cent of the former, then the expression may be simplified thus:

$$\frac{E_2}{E_1}=\frac{R_2}{R_1}.$$

Substitute known values and find E_1.

129.

Ap.: Bunsen cell, rheostat, galvanoscope, and two double connectors.

a. Divided circuit. Join in circuit the cell and galvanoscope and note the deflection. Shunt the circuit at the points *a* and *b* (Fig. 49) by connecting these points across by a wire introduced into the connectors. Note and explain the change in deflection. Open the shunt at some point and introduce the rheostat *R*. Introduce resistance gradually (say .1 ohm at a time) into the rheostat. Note and explain the changes of deflection.

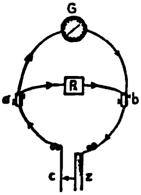

FIG. 49.

130.

Ap.: galvanometer, three Bunsen cells, rheostat, and a plank 4 x 4 x $\frac{3}{4}$ in., having a hole $\frac{1}{2}$ in. diameter and $\frac{1}{2}$ in. deep bored in the center. The hole is nearly filled with mercury, and a wire, *A* (Fig. 50), leading from the galvanometer, *G*, is fastened by staples to the top of the board and is carried to the hole and bent downward into the mercury. This cup has three extra wires, *B*, *C*, and *D*. Between the galvanometer and the battery is introduced the rheostat, *R*. The three cells are connected in series.

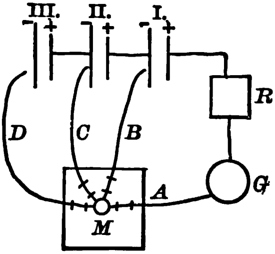

FIG. 50.

a. Introduce into the rheostat a resistance of (say) 30 ohms, and connect *B* with the negative element of cell I. Note the deflection in degrees.

b. Remove wire *B*, connect the wire *C* with cell II., and note the deflection.

c. Remove *C*, connect *D* with cell III., and note the deflection.

d. In which of the three cases is the entire resistance of the circuit greatest? Why?

e. Tabulate the results, including the tangents of each of the deflections and numbers expressing the relative strengths of currents, regarding the least as a unit.

f. How do you account for the changes in the current?

131.

a. Place all the switches of the rheostat on zero. Repeat Ex. 130 and tabulate the results.

b. In which of the two cases do your two tables show that the addition of cells makes greater improvement in the current? Why?

132.

Ap.: galvanometer, rheostat, three Bunsen cells, two blocks (*A* and *B*) containing holes filled with mercury. (Connections are made as shown in Fig. 51.)

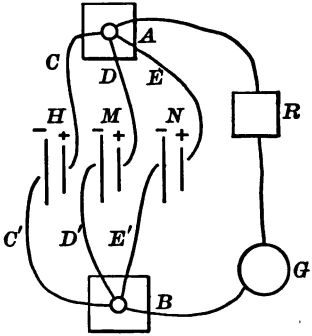

FIG. 51.

a. Introduce a resistance of 30 ohms into the rheostat. Close the circuit through cell *H* by wires *C* and *C′*, and note the deflection obtained.

b. Next introduce, together with cell *H*, cell *M*, in arc, by wires *D* and *D′*, and note the deflection.

c. Finally introduce, in conjunction with the others, cell *N*, and note the deflection. Tabulate the deflections, their tangents, and relative strength of currents.

133.

a. Place all the switches of *R* on the zeros, repeat the last experiment, and tabulate the results as in that experiment.

b. In which of the last two experiments, as shown by the two tables, is the addition of cells most efficient in increasing the current?

c. What general rule for joining cells is verified by the last four experiments?

134.

Ap.: six Bunsen cells, connected in series; an incandescent lamp, whose resistance does not exceed 9 ohms; two double-connectors, joined by a piece of platinum wire, not exceeding ½ in. in length, and in size from No. 32 to No. 30, B. & S. G., and mercury cup, *M*.

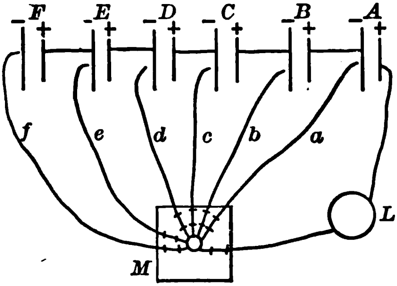

FIG. 52.

a. Introduce cell *A* (Fig. 52) into circuit with the lamp by joining *a*; then add *B*, first removing *a* and then joining *b*; and so on until all the cells are in circuit. Note at each time any change observable in the lamp.

b. Now substitute for the lamp the platinum wire, and repeat, noting any changes in the wire observable.

c. Next connect two cells in arc by means of the two mercury blocks, as in Fig. 50, and introduce the lamp into the circuit. Add cell after cell in arc, and note the effect on the lamp.

d. Substituting the platinum wire for the lamp, repeat and note the effects.

e. Considering that the resistance of the lamp is several ohms, while that of the platinum wire is a small part of an ohm, what facts do the last two experiments establish?

135.

Ap.: as in the last four experiments, except for the galvanometer is substituted the primary coil, *A* (Fig. 53), supported (in a vertical position, with the small end down) by a ring-stand and clamp. The core should be in the coil, and should be wedged in with papers, so as not to fall through the coil or be easily pulled through. An armature of soft iron, about 1 x 1 x $\frac{3}{16}$ in., with a hook in the center, is provided; also a spring balance graduated in ounces.

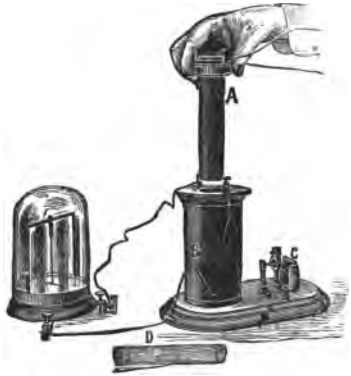

FIG. 53.

Repeat each of the last four experiments in order, but instead of seeking for a deflection when the circuit is closed in each instance, apply the armature to the lower end of the projecting core, hook the spring balance on to this, and measure the force necessary to pull the armature off, adding, in each case, to the force indicated by the index of the balance, the weight of the armature and balance. Several trials should be made in every case, and the mean of the results taken.

Tabulate the results in each of the four experiments, stating the number of cells used, how connected, what resistance in the rheostat, and the force employed to remove the armature.

b. Draw useful lessons from this table.

136.

Ap.: primary and secondary coils and core of soft iron wires (*A*, *B*, and *D*, Fig. 53), magnetic needle, battery, galvanoscope with astatic needle, and bar magnet.

a. Suspend in a horizontal position in a sling the core *D*.

Take the primary coil *A*; introduce the leading-out wires of battery into the screw-cups. Hold the free end of the coil close to one end of the core in such a position that the latter might enter the former. State what occurs.

b. Hold the free end of the coil near the N.-seeking pole of the magnetic needle, then near the S.-seeking pole. State what occurs in each case.

c. Shift the battery wires from cup to cup so as to reverse the current through the coil, and see if the polarity of the coil is reversed.

d. Does the free end now attract or repel the N.-seeking pole of the needle? Then what is the polarity of the free end? Does the current at this end flow in the direction in which the hands of a clock move, or the reverse?

137.

Connect the galvanoscope with the secondary coil, thereby establishing a complete electric circuit, but having no battery or other means of creating an electric current in it. Set the galvanoscope at zero. Thrust the primary coil, through which a current is passing, quickly into the secondary coil, and notice whether a small deflection of the needle occurs at the same instant, and if so, in what direction. As soon as the needle is quiet, withdraw the primary from the secondary, and notice whether another deflection occurs, and in what direction.

138.

Put the core into the primary coil, and repeat the last experiment and state whether any difference in the results are observable.

139.

Determine, by holding it near a magnetic needle, whether the free end of the primary coil is a N.-seeking or S.-seeking pole; see in what direction the needle is deflected when it is introduced into the secondary coil. Then thrust the corresponding end of the bar magnet alone into the secondary coil; note whether there is a deflection produced, and if so, whether it is in the same direction as when the corresponding pole of the coil was introduced. Withdraw the magnet and state what occurs.

140.

a Place the primary coil and its core in the secondary coil, and when the needle is quiet, break the primary circuit and note any deflection which may occur at the instant, and its direction.

b. Close the circuit and note what occurs.

141.

Introduce the battery wires into the screw-cups on the platform containing the secondary coil. The automatic make-and-break piece is thrown into rapid vibration (possibly it will be necessary to turn the screw on the top of this piece up or down a little). Open the circuit at some point and introduce the primary coil, securing a couple of feet of slack wire; remove the core and introduce the primary into the secondary coil, first having removed the galvanoscope from the secondary circuit and having attached some metallic handles to the free ends of these wires. Grasp the two handles in your two hands (*no danger, or painful results need be feared*). Still holding the handles, pick up the core and bring one end of it down slowly into the primary coil. Do not continue this to the point that it becomes painful. How are the currents which you feel generated?

142.

Ap.: bar magnet and an exploring needle.

Explore the field of a magnet for the directions of lines of force, and map the same. Lay the bar magnet on the opposite page so that one end will be about at the center of the page. Trace the surface covered by the magnet with a pencil. Suspend the needle beside the bar, near its end, but not touching it; place two points on the paper, as *A* and *B*, Fig. 54, directly under the two ends of the needle. Then move the needle in the direction in which it points, and place it so that the end which was over *A* will be over *B*; mark the new location of the remote end of the needle, as *C*. Continue this operation as far as may be and then draw a curved (?) line through these points. This line will represent approximately the direction of a line of magnetic force. Draw in the same manner a series of lines of force, starting each time from a new position with reference to the bar. Find (at least approximately) the apparent point of convergence of these lines. This point is the true pole of the magnet.

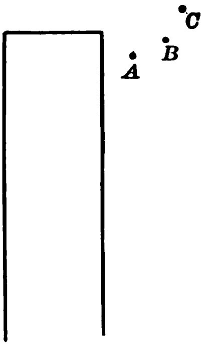

FIG. 54.

143.

Ap.: bar magnet, exploring needle, and half-sheet of foolscap.

Verify the law of magnetic force, viz.: *When a magnetic pole attracts or repels another magnetic pole, the force varies inversely as the square of the distance between them.* Place the magnet on the paper, run a pencil along its edges, marking on the paper the location of the magnet. Take some point on the paper within the field of the magnet, as *A*, Fig. 55. The poles of a magnet, *i.e.* the points of greatest magnetic intensity, are not quite at the extremities of the magnet, but for present purposes may be regarded as at points *N* and *S*,

about one-fifth of an inch (0.5^{cm}) from the ends *N* and *S′* of the magnet. Now if an N.-pole were placed at *A*, it would be repelled along the line *NA* and attracted along the line *AS*. Since the poles *N* and *S* have equal strength, if the law of magnetic force be true, the force acting along the line *AS* will be less than the force acting along the line *NA* in proportion as the square of the distance *AS* is greater than the square of the distance *AN*. Measure *AN* and *AS*; produce the line *NA* and construct a parallelogram, *ACDB*, making

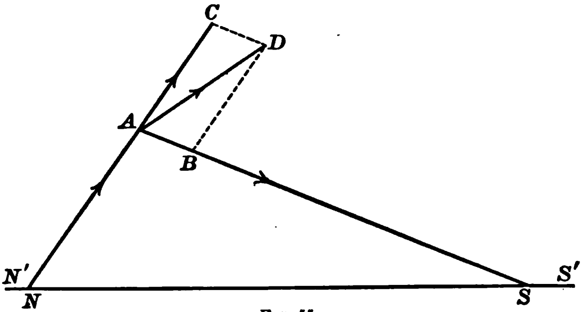

FIG. 55.

$$AC : AB :: AS^2 : NA^2;$$

then *AD* represents in magnitude and direction the resultant of the two forces acting on *A*. Remove the magnet and suspend the exploring magnet so that its N.-pole will be over and near *A*. Turn the paper around so that the needle will be over and parallel with the line *AD*; in other words, so that *AD* will lie in the magnetic meridian. Replace the magnet on the paper in its former place. If, when the needle comes to rest, it is still parallel with *AD*, the law is shown to be true; for it is evident that under no other conditions would the needle retain its position in the magnetic meridian, the effect of the two forces being simply to produce a motion along the line *AD*.

144.

Ap.: pane of thin window glass; two thin strips of wood about $\frac{3}{16}$ in. thick; fine wire sieve; fine iron-turnings; circular magnet, *i.e.* a circular disk of steel about 2 in. diameter and $\frac{1}{8}$ in. thick, magnetized in the direction of one of its diameters; a solution of tannin, blotting-paper, and white paper similar to that used in this book.

Make a map of the field of a magnet showing the direction of the lines of magnetic force. Place the glass over the magnet lying on a table so that the magnet will be at the center of the glass, and support the glass at its opposite ends on the strips of wood. Sift iron-turnings (previously broken fine in a mortar) through the sieve very sparsely over the glass plate. Tap the glass at different points near its edges with the end of a lead-pencil. When the filings in the vicinity of the magnet have arranged themselves satisfactorily, wet one side of a sheet of white paper with the solution of tannin; commencing at one end, lay the wet side carefully on the turnings, place the blotting-paper over this paper, and press gently upon them with the hand. Now raise the white paper from the glass carefully, so as not to disturb the adhering turnings; put it aside to dry, and, when dry, brush off the turnings. Marks will be made by chemical action between the tannin and iron wherever the latter touches the paper. When dry, paste with mucilage the copy of the curves on the opposite page.

145.

a. Produce on the glass plate, as before, lines of turnings, representing the magnetic curves. Take an exploring needle (consisting of a piece of magnetized knitting-needle $\frac{5}{8}$ in. long, suspended at its center with a bit of wax from a shred of unspun silk) and carry it around the disk, just outside its edge. Does the needle tend to place itself parallel (*i.e.* in a tangential position) with the lines of force at every point?

b. Imagine the disk to represent a great circle of the earth passing through its magnetic poles; carry the needle around it again and note any correspondence that you may observe in its behavior with that which happens when a needle is transported along a magnetic meridian of the earth.

146.

Ap.: magnetic needle poised on a steel point on a stand, bar magnet, voltaic cell, and a time-keeper.

a. Compare the magnetic moments of the same magnetic needle (virtually its sensitiveness) *under different conditions.* The directive force of the earth's magnetism, which causes a needle to rotate until it comes into line with the earth's magnetic meridian, is a mechanical couple. The *magnetic moment of a needle* is the moment of this couple. The greater its magnetic moment, the quicker the movement of the needle and the greater the number of oscillations it will make in a given time after being turned aside from its normal position (*i.e.* the magnetic meridian of the earth). On the other hand, the smaller the magnetic moment of a needle, the smaller the force required to turn it aside (*i.e.* to deflect it); hence the more sensitive the needle.

Stretch a portion (say about 3 ft.) of the battery wire horizontally between two fixed points, so that the needle, when placed under it, will be about half an inch below it. The wire should lie in the magnetic meridian, which may be found

with the needle. Place the needle under the wire; there being no current in the wire, the needle and wire are parallel. Turn the needle one side through an angle of about 45° and count the number of vibrations it makes in (say) a quarter of a minute.

Then place a bar magnet on a pile of books or blocks, so as to be on the same level with the needle. Place the magnet in the magnetic meridian with its N.-pole facing the N.-pole of the needle, and three to six inches distant, so manipulating as not to cause a deflection of the needle. Again deflect the needle with the hand and count the number of vibrations made in the same period of time as before.

Representing the number of vibrations in the first case by N_1, and in the second case by N_2; the magnetic moment in the first case by M_1, in the second case by M_2; then

$$M_1 : M_2 : : N_1^2 : N_2^2.$$

Find the ratio between the magnetic moments in the two cases. [See Law of Pendulum, § 84, "Elements of Physics."]

b. Close the circuit through the wire, and when the needle comes to rest, stick a pin in the table vertically under its N.-pole. Remove the bar magnet and notice any change in the deflection of the needle and *account for it.*

SOUND.

147.

Ap.: wooden rod, *e.g.* a yard-stick; a rubber cord 12 ft. long and $\frac{3}{16}$ or $\frac{1}{4}$ in. in diameter (such as is used for buffing is best), and weight (say $\frac{1}{2}$ lb.). [It may be necessary to use this cord out of doors, suspending it from a tree or other elevated object, as a shorter cord would increase the difficulties of the experiment. Two pupils are required to work together.]

Suspend the cord vertically by means of a staple driven into some elevated object, so that the lower end will be about 2 ft. from the ground. Make a slip noose in a string and with it attach the weight to the lower extremity of the cord. Place some boxes loosely against the weight on two opposite sides so as to prevent the weight from swinging.

Apply the rod to the cord from 8 to 10 in. above the point from which the weight is suspended, pressing laterally against the cord, and by trial timing the movements of your rod so as to produce stationary vibrations in the cord. You will have succeeded in this when the cord and rod do not separate during the movements. As soon as you have succeeded in this, let your assistant count the number of vibrations made in (say) twenty seconds. Get the number of vibrations made when the cord is occupied with only one ventral segment; *i.e.* when the antinode is in the middle of the cord and nodes only at the extremities; also when there are two, three, and, if practicable, four ventral segments.

a. How does the number of vibrations made by the cord when occupied by two segments compare with the number made when there is only one segment?

b. How does the number of vibrations made by the cord when there are three segments compare with the number made when there is one segment?

c. State the relation which exists between the rate of vibration of a cord and the number of segments into which it is divided.

a. Measure the length of the vibrating cord, *i.e.* the distance beween the two extreme nodes, and determine in each case the length of the segment. Assuming that each segment is half of a wave-length, and that there are as many waves generated in a given time as there are complete vibrations made by the rod (or, which is the same, the number of impulses given to the cord by the rod), compute the velocity with which the waves traverse the cord.

e. How do the velocities with which the waves of different lengths travel compare?

148.

Ap.: as in Ex. 147; the weight being attached near the lower end of the cord.

Grasp loosely the cord, just above the weight, between the thumb and finger; strike the cord a little above the hand a quick but not very forceful blow with the rod and count the number of pulsations felt by the hand in a given time, *e.g.* five or ten seconds, and determine the rate of vibration. Then raise the weight, attaching it at a point so that the vibrating portion of the cord is as nearly as practicable one-half as long as before. Ascertain the rate of vibration as before.

How is the rate of a vibration affected by the length of a vibrating cord? Why should it be thus affected?

149.

Ap.: as in Ex. 148, except that the weight is not used.

a. Grasp the lower end of the cord with the hand, stretch the cord a little, holding the hand against your knee, so as to keep it steady and keep the cord at a uniform tension. Strike the cord with the rod just above your hand and count the number of pulsations felt by the hand in some definite time (say ten seconds) and determine the rate of vibration. Then increase the tension of the cord, preserving the same length by grasping the cord farther up, and ascertain the rate of vibration as before. How is the rate of vibration affected by change of tension?

b. Determine the wave-length in each case.

150.

Ap.: ring-stand, glass funnel, rubber tube; glass tube about 18 in. long and 2 in. bore, having a cork (perforated by a small glass tube) inserted in one end (the whole arranged as in Fig. 56); measuring-stick, centigrade thermometer, and a diapason whose vibration number is known.

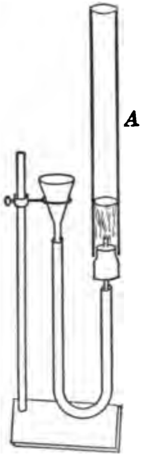

Fig. 56.

a. Pour water into the funnel; set the diapason in vibration; hold it over and near the orifice of the tube, *A*; raise or depress the tube until the tube gives the maximum re-ënforcement of sound; then place the thumb-nail at the surface of the water and measure from this point to the upper end of the tube. Add to this measurement 0.3 the diameter of the bore: the sum is one-fourth the wave-length produced by the diapason. Find the wave-length.

b. Deduce from the equation,

$$\text{Wave-length} = \frac{\text{velocity}}{\text{vibration number}},$$

the velocity with which the air transmits sound.

c. Verify the last result as follows: Take the temperature of the room; to 1090 ft. add 1.69 ft. for every degree above 0° C.; or velocity at $T°(\text{F.}) = (1058 + T)$ ft. nearly.

d. Assuming the velocity and knowing the length of the resonant column, deduce the vibration rate or pitch of the diapason.

151.

Ap.: three iron balls suspended at equal distances apart, two of them, *A* and *B* (Fig. 57), by strings about 1^{m}. long, so as to have the same vibration numbers; the other, *C*, about 5^{cm} shorter. At about $\frac{1}{4}$ their length from their points of suspension, a taut thread connects them, being tied to them at points *a* and *b*, and attached at *c* by a wire hook.

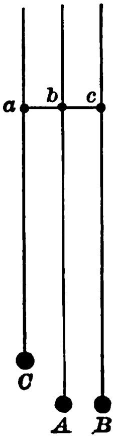

Fig. 57.

a. Raise *A* a little way (not exceeding 25^{cm}) and let it swing; observe for a considerable time, and state the peculiarities of the vibrations caused in *B* and *C* by the periodic impulses communicated to them from *A* through the thread.

b. State clearly the nature and cause of sympathetic and forced vibrations, as shown by this experiment.

152.

a. Disconnect the thread at *c*, raise both *A* and *C*, and set both in vibration at the same instant. Watch in hand, note the number of seconds which intervene beween the start and the instant when the two balls first pass the centers of their arcs in opposite directions. Next note the interval which elapses from this instant until the two balls reach the extremities of their arcs on the same side at the same time.

b. During which of these periods of time is the mutually destructive interference on the increase?

c. During which of these periods is the destructive interference on the decrease?

d. When is the destructive interference greatest?

e. When is the destructive interference least; or, in other words, the resultant effect of the two motions greatest?

f. Suppose these two pendulums act simultaneously on the same body of air; when would the resulting condensation be the least? the greatest?

g. Suppose the vibrations were frequent enough to produce sound-waves; at what instant would these sound-waves be most [illegible] least intense?

153.

Ap.: sonometer, lump of iron or stone, balance, metric micrometer calipers, and meter-stick.

Show, other things being the same, that the vibration rate of a stretched string varies inversely as its length.

a. Use two wires of the same size and stretch each with equal force. Pluck both wires in the middle; do both give the same note?

b. Insert the bridge so as to divide one of the strings into two equal parts. Pluck one of the halves in the middle; what musical interval do you find between the note given and the note given by the other string? Inference.

154.

Show, other things being the same, that the vibration rate varies as the square root of the stretching force.

Take two similar wires and apply four times the stretching force to one that you do to the other. Pluck both; what musical interval is there between them? Inference.

155.

Combine results of Ex. 153 and 154. Take two similar wires, stretch them with unequal forces (*e.g.* as 4:1). Use the whole length of the wire which is stretched most, insert the bridge under the other wire, and move it until the two give the same note. Verify the following: —

$$\frac{\sqrt{W}}{L}=\frac{\sqrt{w}}{l}, \text{ or } \frac{T}{L^2}=\frac{t}{l^2},$$

in which $T=$ the tension of wire A, and $L=$ its length; and $t=$ the tension of wire a, and $l=$ its length.

156.

Find, using the above equation, the weight of a lump of iron or a stone fastened to one wire and used as a stretching force, having obtained unison by shifting either its bridge or the bridge of the other wire which is stretched by a known force. Verify the computed weight of the iron (or stone) by weighing it.

157.

Show, other things being the same, that the vibration rate varies inversely as the thickness of the wire, or as the square root of the weight of the wire.

Take two wires of different thicknesses and stretch them with equal forces. Place a bridge under the thicker wire and move it till it is brought into unison with the other. Let N and n represent the vibration numbers of the two wires, D and d, their respective diameters, W and w, their weights, and L and l their lengths. Verify the following:

$$\frac{L}{l}=\frac{D}{d}.$$

Now $N:n::\frac{1}{L}:\frac{1}{l}$; then $N:n::\frac{1}{D}:\frac{1}{d}$; *i.e.* the vibration rate varies as the reciprocals of the diameters; in other words, *inversely as the diameters.* But $\frac{D}{d^2}=\frac{W}{w}$, or $\frac{D}{d}=\frac{\sqrt{W}}{\sqrt{w}}$; hence $N:n::\frac{1}{\sqrt{W}}:\frac{1}{\sqrt{w}}$; *i.e.* the vibration rate varies inversely as the square roots of the weights.

158.

Ap.: as in last experiment; also an adjustable tuning-fork, whose vibration number is known, and two thin temporary bridges made of shingles.

a. Bring two similar wires, full length, into tune with the fork by varying their tension. Divide the length of one of the wires with a bridge, and verify, as nearly as the ear will admit, the vibration lengths corresponding to the ordinary musical scale, tabulating the results as follows: —

SCALE.	NOTE.	Vibration number.	Vibration lengths.
Tonic	C	$n =$	$l =$
Second	D	$\frac{9}{8}\,n =$	$\frac{8}{9}\,l =$
Major Third	E	$\frac{5}{4}\,n =$	$\frac{4}{5}\,l =$
Fourth	F	$\frac{4}{3}\,n =$	$\frac{3}{4}\,l =$
Fifth	G	$\frac{3}{2}\,n =$	$\frac{2}{3}\,l =$
Major Sixth	A	$\frac{5}{3}\,n =$	$\frac{3}{5}\,l =$
Major Seventh	B	$\frac{15}{8}\,n =$	$\frac{8}{15}\,l =$
Octave	C	$2\,n =$	$\frac{1}{2}\,l =$

159.

Bring two similar wires, full (and equal) lengths, into tune with the fork by varying their tension. Place bridges under the wires so as to obtain in one wire $\frac{8}{9}\,l$, and in the other $\frac{4}{5}\,l$ ($l =$ full length of the wires). See if the fork and the two strings give the first three notes of the scale, judging by the ear. Adjust the fork to correspond to these notes of the scale and test therewith the pitch of each string. Next try, in a similar manner, the fork and wires, $\frac{4}{5}\,l$ and $\frac{3}{4}\,l$, and so on throughout the scale.

160.

Ap.: organ-pipe with a closely fitting piston and piston-rod by which the open pipe can be converted at will into a closed pipe of any desired length.

Blow very gently into the open pipe and produce its fundamental. Then close the end of the pipe with the piston, and produce the fundamental with the closed pipe of the same length.

Compare the pitch of the two fundamentals.

161.

Thrust the piston into the pipe until the pitch is the same as that given by the open pipe.

Compare the lengths of the two pipes, open and closed, which give the same pitch. Measure from the piston of the closed pipe to the end where the vibrations originate; *i.e.* at the flue.

162.

a. Produce the fundamental of the open pipe, blowing gently, and observe what overtone accompanies it. [In the case of an open pipe the fundamental is never produced by itself.]

b. Increase the force of the blow and ascertain the overtones that are added.

c. See if by blowing hard you can extinguish the fundamental and so cause the sound to jump up an octave or more.

LIGHT.

163.

Ap.: optical bank (Fig. 58) with three sliding riders; short piece of gas-pipe, *D*, terminating in a burner; several lava-tips of different delivery; standard candle; glass U-tube, *E*, containing water, which may be connected by a rubber tube with a gas-pipe. The number of cubic feet of gas consumed per hour by each tip for each centimeter of difference of level, *FG* (representing the pressure), in the U-tube, must be known, and can be readily ascertained by teacher or pupil with the use of a gas-meter found in every building supplied with gas. This ap. must be used in a dark room, whose walls are painted a dead black, or in a space separated from a light room by black curtains.

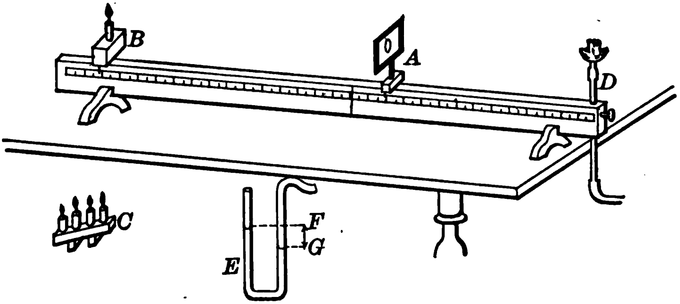

FIG. 58.

Photometry. *a.* Place *A, B,* and *C* on the rail, with *A* between the other two, the extreme riders (say) 200^{cm} apart. Light candle after candle on *C*, noticing whether the contrast between the greased circle and the surrounding ungreased surface is increased or decreased.

b. Is the circle lighter or darker than the surrounding surface on the side turned toward the lights? Explain fully the cause of the difference.

c. Is the circle lighter or darker than the rest of the surface on the side turned away from the lights? Explain.

d. Light the candle on *B* and move *A* back and forth until the circle, viewed on both sides, appears illuminated, as nearly

as practicable, the same as the surrounding surfaces. The observer should view the disk always at the same angle, *i.e.* 45°, and he should wait before taking observations until the candle has reached its normal condition of burning. Measure the distance of the screen from both *B* and *C*, using the scale on the side of the rail and locating each rider by the points on the scale indicated by the needles beneath the riders.

e. The two sides are now, theoretically, equally illuminated. If *B* and *C* were equally distant from the screen, the side turned toward *C* would be illuminated how many times more strongly than the side facing *B*?

f. Now that the two sides of the screen are equally illuminated, the four candle flames are how many times as far from the screen as the single flame?

g. What law expressing the relation between distance and intensity of light is, at least approximately, verified by this experiment?

164.

a. Place tip (say) No. 1 (the lava-tips should be kept in small pasteboard boxes with the numbers of the tips and their rates of consuming gas per quarter-inch of *FG* written on them) in *D*, and connect *D* with *E* by a rubber tube; turn on the gas and measure *FG*. This measurement represents the pressure at the time. Determine the number of cubic feet of gas that would be consumed per hour with this tip and at this pressure, the number of cubic feet for each quarter-inch of *FG* for this tip being known; *i.e.* having been previously ascertained by teacher or pupil with a gas-meter and a pressure-meter, *E*.

b. Place the rider, *B*, containing a standard candle in position, and move it back and forth until the spot is least distinguishable *on both sides*, when viewed as directed above. Measure the distances *AD* and *AB*. From these distances compute the relative intensities of the two flames; in other words, the candle power of the gas flame.

c. Tabulate your results as follows: —

Tip.	Dist. *AB*.	Dist. *AD*.	Pressure *FG*.	Cu. ft. per hour.	Candle power.	Candle power per cu. ft.
No. 1						

[The State law of Massachusetts requires that "illuminating gas, when burning at the rate of five cubic feet per hour, under favorable conditions, as in an argand burner, with proper air supply, should give out a light equivalent to that of at least fifteen candles." Less than this would indicate an inferior quality of gas.]

165.

Ap.: piece of thin tin about 10 x 5^{cm}, having a hole, *A* (Fig. 59), 5^{mm} in diameter; a pin-hole, *B*, and three pin-holes, *C*, 2^{mm} apart; some wax tapers, used by smokers, and a biconvex lens.

a. In a dark closet hold the tin 2 to 4 in. from a white wall, and a lighted taper 1 to 2 in. on the other side of the tin. Hold the flame consecutively opposite *A*, *B*, and *C*. Make drawings of the images projected through the holes in the three positions, representing as nearly as possible, by shading with the pencil, the relative intensities of the light in the different images and in different parts of the same image, greater depth of shading representing greater intensity of light.

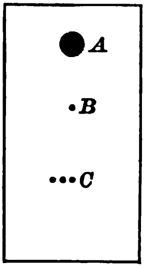

FIG. 59.

b. How do the images formed through *A* and *B* compare in intensity and distinctness? What explanation for the differences do you discover by a thoughtful attention to the images formed through *C*?

c. Introduce the lens between the tin and the wall, and focus the image of the flame sharply on the wall. Of what benefit is the lens in projecting images?

166.

Ap.: concave mirror, measuring-stick, and ring-stand with clamp.

Find the focal length of a concave mirror. *a.* Place a visiting-card in the clamp of the ring-stand. Support the mirror with the stand so that, exposed to the direct rays of the sun on a clear day, it will throw a *circular* image of the sun upon the card. If the image is not a circle, it shows either that the rays do not fall upon the mirror parallel with its axis, or that the card has not a suitable inclination. Reduce the image to a minimum size (which should not exceed 3 or 4^{mm} diameter), by moving the card nearer the mirror or farther away, as the

case may require. Then measure the distance of the card from the apex of the mirror.

b. Why cannot the reflected rays be brought quite to a point?

167.

a. Conjugate foci. Place a candle flame at a little greater distance from the concave mirror than its focal length, so that its image will be thrown upon a screen not farther than two meters from the mirror. Then place the candle flame where the screen was, and place a small screen where the candle flame was. Are the object and image interchangeable? Why?

b. Make a drawing illustrative of your experiment.

168.

a. Place the candle flame nearer the mirror than its principal focus. Describe in full the image formed.

b. Make a drawing illustrative of this experiment.

169.

Ap.: concave mirror and two metric rulers.

Find the distance of the center of curvature of the mirror from its apex.

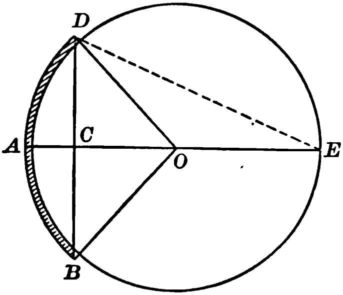

FIG. 60.

Measure its diameter, BD; also its depth, CA. There should be added to the latter the thickness of the glass, inasmuch as the posterior surface is the real mirror. The thickness may be measured approximately with the eye by placing on the anterior surface a point of a pencil and estimating the distance between this point and the image of this point. One-half of this distance is, approximately, the thickness of the glass.

By geometry, $\overline{CD}^2 = AC \times CE$; whence $CE = \frac{\overline{CD}^2}{AC}$

$$AE = CE + AC. \quad AO = \frac{AE}{2}.$$

170.

Verify experimentally the distance last found. First method. Move a candle flame back and forth in the line of the axis of the mirror until the flame and its image coincide. Measure the distance of the flame from the apex of the mirror.

171.

Second method. Place a candle flame in the axis of the mirror and move it back and forth until the diameter of the circle of light cast upon a white wall, not far distant, is equal to the diameter of the mirror. It is evident that the flame is now located at the principal focus, or half-way between the center of curvature and the apex of the mirror. Measure this distance, a, and see if $2a =$ the estimated distance, AO.

172.

Ap.: pencil, dividers, and metric-rule.

Determining the paths of refracted rays. Draw a horizontal line, *AB*, to represent the boundary surface between two optical mediums of different density. Draw an oblique line to represent a ray of light moving in one of the mediums, *M*, and incident upon the boundary surface at point *C*. Continue this line in a broken line into the other medium, *N*, representing its path if it did not suffer refraction. With *C* as a center draw a circle, and represent the sine of the angle of incidence and measure its length. Select one of the mediums named in the following table as the medium in which lies the incident ray; write the name of this medium in a suitable place, *i.e.* above or below *AB*. Select from the table another medium, in which shall lie the refracted ray, and write its name in a suitable place. Determine from the absolute indexes of refraction of the two mediums the index of refraction in passing from *M* into *N*.

Draw the sine of the angle of refraction and the refracted ray. Place arrow-heads in the incident and refracted rays.

TABLE OF MEAN ABSOLUTE INDEXES.

Air at 0° C., and 760^{mm} pressure	1.000294
Pure water	1.33
Alcohol	1.37
Spirits of turpentine	1.48
Humors of the eye (about)	1.35
Carbon bisulphide	1.641
Crown glass (about)	1.53
Flint glass	1.61
Diamond (about)	2.5
Lead chromate	2.97

173.

Ap.: porte lumiere, adjustable slit, glass prism (60°), bisulphide of carbon prism, protractor, three darning-needles.

Determine the index of refraction of a glass prism.

a. Project with a porte lumiere and adjustable slit a very narrow ribbon of light obliquely upon the prism, as *AB*, Fig. 61. Let the prism intercept the light so as to suffer the least deviation; in other words, so that the angle *DCE* will be as small as possible. This result may be secured by rotating the prism about its axis until the image formed on a screen, intercepting the emergent beam, *GE*, departs least from the line *AD*, or until the angle of emergence, *NGE*, equals the angle of incidence, *MBA*. Place a needle vertically at *B*, the point where the ribbon is incident upon the prism; set a second in the path *GE*, so as to cast a shadow on the screen in the yellow part of the spectrum. Remove the prism and insert a needle, *D*, in the shadow cast by the needle *B*. Connect points *B* and *D* by a straight line; also *E* and *G*, continuing it to meet *BD* in *C*. Measure with the protractor the angle of deviation, *DCE*. Now if a, the angle of the prism, = 60°, and b represents the angle of deviation, then i (the index of refraction for yellow light) $= \frac{\sin \frac{1}{2}(a+b)}{\sin \frac{1}{2} a}$. (See Table of Trigonometrical Functions.)

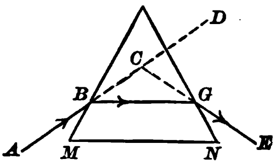

FIG. 61.

b. Determine in a similar manner the index of refraction of carbon disulphide.

174.

Ap.: beaker nearly full of water, and glass test-tube.

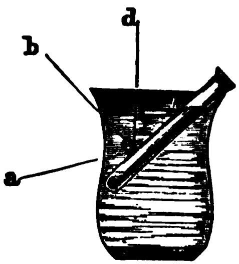

Fig. 62.

Total reflection. *a.* Thrust the empty tube obliquely into the beaker of water and look vertically, *de* (Fig. 62), down upon the submerged portion of the tube; note the appearance of its surface and explain.

b. Can you see through this portion of the tube, looking in the direction indicated above? Why?

c. Pour water into the tube to a depth of about one inch and repeat the experiment. Note and explain any change of phenomena.

175.

Ap.: porte lumiere; glass bulb, *A* (Fig. 63), about 3^{cm} diameter, filled with filtered salt water or carbon disulphide; a white cardboard screen, *B*, having a circular hole, *C*, in the center, whose diameter is a little less than the diameter of the bulb.

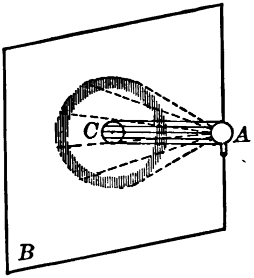

Fig. 63.

a. Produce a "miniature rainbow." Project a beam of light through the aperture in the cardboard, upon the bulb held in the hand, or in a ring-stand clamp; move the bulb back and forth in the beam until the best spectrum reflected from the bulb is thrown upon the cardboard. [It is well to cover the aperture of the window-screen with sheet iron, leaving an aperture a trifle smaller than that in the cardboard, so as to exclude all light except that which strikes the bulb.]

b. If an eye were placed at any spot where red appears on the screen, what color would it see in the bulb? What would be necessary in order that the eye may see blue in the bulb?

LENSES.

176.

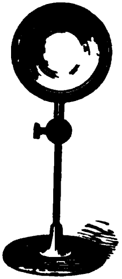

FIG. 64.

Ap.: biconvex lens (Fig. 64); measuring-stick; ring-stand and clamp holding a piece of chalk having a smooth, flat surface.

Ascertain the focal length of the lens. Expose the lens to the sun's direct radiation, and project upon the smooth surface of the chalk the smallest circular spot practicable. Measure the distance from the spot to the nearest point of the lens, and add to this distance one-half of the greatest thickness of the lens.

177.

a. Calculate the magnifying power of a lens from the formula: —

$$\text{Magnifying power} = \frac{10 \text{ in.}}{f} + 1,$$

in which $f =$ focal length, and 10 in. is assumed to be the minimum distance of distinct vision of the average eye.

b. Verify your calculation by a process similar to that given in Ex. 201, for finding the magnifying power of a telescope.

178.

Ap.: same as in Ex. 176, except that a cardboard screen replaces the chalk; also candle and visiting-card.

a. Place the candle flame at the focal distance from (*i.e.* at the principal focus of) the lens, and see if you can get an image of the flame upon the screen.

b. Interpose between the lens and candle flame, and near the latter, the visiting-card having a pin-hole in it, keeping the flame at the principal focus. Place the screen at different distances from the lens and see whether the size of the circle of light changes. Does this experiment verify your estima-

tion of the focal length of the lens? If so, how? Why is the card necessary in this experiment?

c. With the card still in position, move the flame nearer the lens than the principal focus and state and explain the result as it appears upon the screen.

d. Move the flame to a greater than the focal distance from the lens and see, by moving the screen back and forth, if you can catch a distinct image of the flame. If so, describe it.

179.

Are object and image interchangeable as regards their relative distances from the lens and with reference to magnitude?

Cast a distinct image of a candle flame on the screen. Measure the distance of both the flame and the image from the optical center of the lens. Measure any dimension (*e.g.* length or width) of the flame. Let the flame and screen change places, and see if a distinct image is now cast upon the screen and if the corresponding dimensions of the object and image are interchanged.

180.

Make suitable measurements and verify the law that *the corresponding dimensions of an object and its image, formed by a convex lens, vary as their respective distances from the optical center of the lens.*

181.

a. Verify the formula —

$$\frac{1}{f}=\frac{1}{a}+\frac{1}{b}, \text{ or } f=\frac{ab}{a+b},$$

in which $f =$ focal distance, $a =$ distance of object, and $b =$ distance of its image, all measured from the optical center of the lens.

b. If the distances of an object and its image from the optical center of a convex lens are respectively 15 in. and 45 in., what is its focal length?

182.

Ap.: convex lens (Fig. 64) covered on one side with a card containing holes about 8^{mm} diameter, arranged as in Fig. 65 (this card may be attached to the mounting of the lens); paper or cardboard screen, and metric ruler.

a. Spherical and chromatic aberration. Place the lens with the covered side turned toward the sun (or distant gas flame), so that the rays will fall upon it as nearly parallel with the axis as possible. Place the card screen near the lens on the other side; move it slowly away until the elongated images of 1, 2, 3, and 4 meet at a point. Measure the distance of the screen at this point from the optical center of the lens.

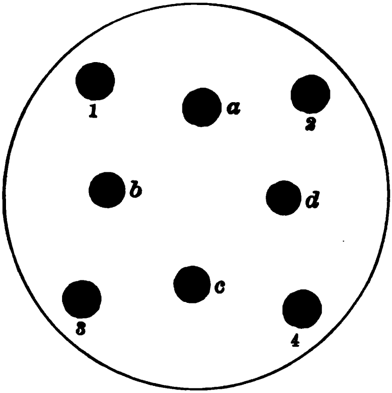

FIG. 65.

b. Make a drawing of the entire images formed by the eight holes.

c. A portion of the light that passes through 1, 2, 3, and 4 is now brought to the same focus; why is not all the light from these holes brought to a focus?

d. Is there any evidence of dispersion of the light which passes through 1, 2, 3, and 4? If so, what is the evidence? What technical name is given to this phenomenon?

e. Move the screen still farther from the lens until the light from *a*, *b*, *c*, and *d* meets at the same focus. Does any of the light from 1, 2, 3, and 4 meet at this focus? Why does not the light from all the holes have the same focus? What name is given to this phenomenon?

f. Make a drawing of the several images as they now appear upon the screen.

183.

Ap.: porte lumiere, Fig. 66 (for an inexpensive lumiere, with conveniently adapted accessories for *physical experimentation*, as indicated in this manual, the author knows of none equal to his own); adjustable slit, mounted lens (Fig. 64) 10 in. focus and 5 in. diameter; white cardboard screen (about 2½ x 2 ft.), mounted on a light frame (an excellent screen may be made by covering a wooden frame with thick white Holland or white enamelled cloth); a disulphide prism, glass prism, adjustable stand, and slips of blue and red glass.

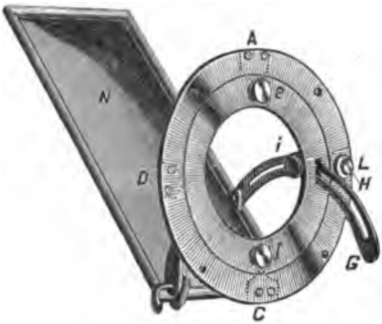

FIG. 66.

Dispersion and the solar spectrum. Place in position the porte lumiere, and in the lumiere the adjustable slit with an opening not exceeding ⅛ in.; support, on a window-shelf (a hinged shelf provided for holding lumiere accessories) or a table, the lens at a distance suitable for projecting a sharply defined image on the screen at a distance from the lens not greater than 6 to 10 ft. Project the image of the slit; measure the distance between the lens and screen; on an adjustable stand, close to the lens, place the glass prism so that the ribbon of light will strike one of its faces obliquely; rotate it slowly on its axis until a colored spectrum is thrown either to the right or left upon a wall of the room. Place the screen so as to intercept the dispersed light, preserving the same distance from the lens that it had before the prism was introduced, and rotate the prism on its axis until the position of least deviation is obtained.

a. Do you discover numerous faint dark lines crossing the spectrum parallel with the color bands? If so, see if by moving the screen a very little toward or from the lens the lines

are increased in number and distinctness; then count all that are visible.

b. Place horizontally across the spectrum a narrow strip of white paper or cardboard, and make a pencil dot on the paper in each dark line; also make a dot at each extremity of the spectrum. Let the dots be heavy or light, according to the depth of the lines.

Make suitable adjustments from time to time (once in about eight minutes) to counteract the effects of the movements of the sun in the heavens. Substitute the disulphide of carbon prism for the glass prism; obtain the position of least deviation (but not so as to crowd the colors together on the spectrum); place another strip of paper across this spectrum; locate as before all the dark lines and the extremities of the spectrum.

Make on the opposite page two rectangular spaces, their length drawn to scale (the width of these spaces may be 15^{mm}), to represent each of the spectra obtained; locate to scale the position of all the dark lines and draw lines of varying weight across the rectangular spaces so as to map as faithfully as practicable the dark-line spectrums.

c. By what name are these lines known, and how are they caused?

d. What difference do you observe in the spectrums formed by the two prisms?

184.

a. Place a slip of red glass over one of the two surfaces of the prism through which the light passes. Describe and explain the spectrum in its changed appearance.

b. Cover with a blue glass and describe the spectrum.

c. Cover with both glasses and state and explain the results.

185.

Ap.: as above; also tank accompanying lumiere, and bottles containing solutions of permanganate of potash, picric acid, ammoniated sulphate of copper, oxide of copper in ammonia. Strong solutions should be prepared and then diluted until the best results are obtained.

a. Between the adjustable slit and lens, and near the former, introduce the tank filled with one of the solutions; describe the spectrum.

b. Rinse the tank thoroughly after each solution is used, and introduce successively each of the other solutions and describe minutely each spectrum.

186.

Ap.: all the spectrum ap. used above, and test-tubes with cork stoppers; some iodine, dilute nitric acid, copper turnings, and an alcohol lamp.

a. *Absorption spectra.* Place a few particles of iodine in the bottom of a clean test-tube; heat over an alcohol flame and fill the tube with a dense vapor of iodine; stopper and quickly place it in front of the adjustable slit. Describe the spectrum.

b. Clean the tube if necessary with alcohol; place in the bottom a few copper turnings; pour upon them a few drops of nitric acid and fill the tube with fumes of nitrous acid; stopper and place the tube in front of the slit. Describe the spectrum.

187.

Ap.: as above; also strips of red and blue cardboard about 18 x 3 in.

a. Project a spectrum on the screen, and place one of the strips of colored cardboard across the spectrum at right angles to the bands of colors. Describe its appearance in the different parts of the spectrum.

b. Is a given color sensation due to some property of the object viewed or to the light by which it is viewed? How does this experiment confirm your statement?

188.

Ap.: as above; also a test-tube containing a dilute solution of eosine, and a white cardboard (6 x 4 in.) painted with a solution of sulphate of quinine acidulated with sulphuric acid.

Fluorescence. *a.* Hold the red solution in the different colors of the spectrum. Do you see any evidence that this solution has a power of changing the rate of ether vibration? Explain.

b. Hold the cardboard lengthwise, so as to overlap the violet portion of the spectrum, and extend into the ultra-violet portion. Note and explain any phenomena you may observe.

189.

Ap.: test-tube one-third full of acidulated solution of sulphate of quinine, on which is poured an equal volume of chlorophyll dissolved in ether. The tube is placed in front of a window and is stoppered to prevent evaporation.

190.

Do not disturb the tube, but examine the liquid contents at the top and bottom, both by transmitted and reflected light; note the appearance of each liquid in each light and explain the phenomena which you observe.

191.

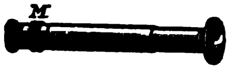

FIG. 67.

Ap.: pocket spectroscope; four platinum wires with glass handles; Bunsen burner or alcohol lamp; bottles of concentrated solutions of sodium, potassium, lithium, and strontium salts.

Absorption and bright-line spectra. a. Open the slit of the spectroscope about $\frac{1}{16}$ in. (Fig. 67); look through the spectroscope at the sky and state what you observe.

b. Focus the spectrum by moving the inner tube back and forth; close the slit so as to admit very little light, and by patient trial obtain as many faint dark lines crossing the spectrum, parallel with the color-bands, as possible. Count the number of lines.

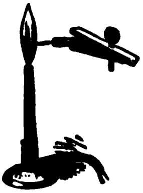

FIG. 68.

c. Dip the platinum wire into the sodium salt solution and support it in the colorless flame (Fig. 68). In a dark room examine the spectrum with a very narrow slit and the instrument well focussed. Describe the spectrum.

d. Repeat the above with each of the salts, using care that *a given wire is used only for a given salt.*

192.

Ap.: porte lumiere, two carbon disulphide prisms, screen, small black cardboard, and convex lens.

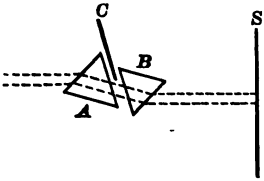

FIG. 69.

Prove; by decomposition and recomposition, that white light is composed of at least seven colors.

Project in the usual way with a porte lumiere, lens, and prism, a spectrum upon a screen at a distance not exceeding a meter. Place a second prism, *B*, in a position (Fig. 69) so as to intercept the dispersed rays and bend them back again. Do you obtain an image of the slit or a spectrum. What is its color? Explain.

193.

a. Separate the two prisms about $\frac{1}{2}$ in. and introduce the black cardboard, *C*, into the interval so as to suppress first the red, then red and yellow; then remove the card and introduce it so as to suppress only the violet and blue, and state and explain the results in each case.

b. This experiment shows that color may be obtained from white light in what manner?

c. What determines the color that will result from this process?

194.

Ap.: rotating ap. and set of prepared circular color-disks.

Mixing colors. *a.* Rotate the Newton's color-disk, containing all the colors of the spectrum, and state the result and the lesson it teaches.

b. Rotate the tricolored disk of red, violet, and green, and state the result and its lesson.

c. Rotate the disk containing only yellow and blue, and state the result and its lesson.

d. Rotate each of the other disks, state the results, and explain.

195.

Ap.: pans of chrome yellow and ultramarine pigments, camel's-hair brush, some pieces of broken crockery ware, and tumbler of water.

Mixing pigments. Wet the brush and take on it some of one of the pigments and paint a space about the size of a two-cent piece on a piece of crockery. Wash the brush of this pigment, take some of the other pigment, and paint another piece of crockery in the same manner. Next mix on a third piece of crockery some of each of the two pigments taken from each of the other painted surfaces. Note and explain the result.

196.

Ap.: small piece of Iceland spar; white card, on which is a black dot, made with ink, about twice the size of a period (punctuation point) on this page; porte lumiere and black cardboard of the size of a slide disk, having a pin-hole in the center.

Double refraction. Lay the spar over the dot on the white card, look through it at the dot, and rotate the spar. Describe fully the phenomena which occur during one complete revolution.

[Caution: the spar must be handled with care, as it is very soft and easily scratched.]

197.

Mount the lumiere; place the black card in the slide-holder; throw a small beam of light through the hole in the card on to a screen a few feet distant. Cover the hole with the spar and rotate it. What explanation does this experiment furnish why the dot in the preceding experiment appears double?

198.

Ap.: pair of tourmaline tongs.

Phenomena of tourmalines. Looking through the pair of tourmaline slices at the sky, rotate one of them, and note and explain the phenomena observed.

199.

Ap.: polariscope, films of mica, and Prince Rupert's drop or glass stopple.

Colors by polarization. *a.* Place on the support *G* (Fig. 70) a film of mica; place the polariscope before a window with *S* turned toward the sky; slowly rotate the analyzer *A* while looking through it at the film; observe the phenomena which occur.

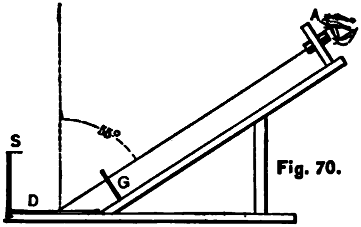

FIG. 70.

b. Through the agency of what two processes is the coloration produced?

c. Place a Prince Rupert's drop on the stage; examine and explain phenomena.

d. How is the light polarized in this instrument?

e. Remove the stage *G*; rotate the analyzer as you look through it at the glass plates *D.* What evidence do you observe that the light is polarized by the glass plates?

200.

Ap.: concave mirror, convex lens, and some object; *e.g.* a bouquet of artificial flowers of various colors.

Reflecting telescope. *a.* Place the object from three to six meters from the mirror and a little to one side of the axis of the mirror. Standing a little on the other side of the axis, place the lens between yourself and the image, and focus it so that you will see the image distinctly through the lens. Describe the image as seen through the lens.

b. What are the essential parts of a reflecting telescope, and what is the office of each part?

201.

Ap.: telescope, meter-stick, and visiting-card.

Determine approximately the magnifying power of the telescope. *a.* Place the meter-stick and card in a vertical position against a wall or board with the bottom of the stick and card on the same horizontal level. Stand 50 to 200 ft. away from them. After properly focussing the telescope so as to see the card, look at it through the telescope with the right eye; at the same time look at the card with the left eye (not through the telescope, of course). Let another person run his finger up and down the stick until it seems (to the left eye) to be on a level with the top of the image of the card (as seen with the right eye). Ascertain the apparent hight (H) of the image, S'; also the hight (h) of the card, S. Let m = the magnifying power sought; then

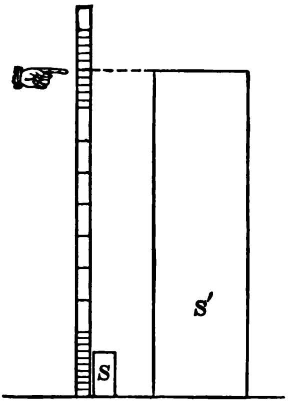

Fig. 71.

$$m = \frac{H}{h}.$$

It is very important that the telescope be firmly supported upon some immovable object during this experiment.

202.

Ap.: common field telescope.

View objects near and far away, and observe whether the eye-glass must be nearer to or farther away from the object glass when the object is near in order to properly focus the image to the eye. Explain.

203.

Ap.: differential thermometer constructed from two 2 oz. flasks; bent glass tube containing colored liquid. One flask is blackened, except its bottom, with soot from a candle flame.

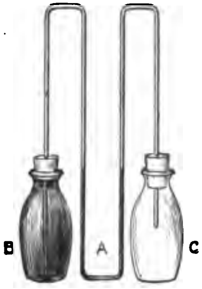

FIG. 72.

Degree of absorption and radiation dependent on the character of the surface.

a. Expose both bulbs of the thermometer to the direct rays of the sun. Note, and explain the effect produced upon the liquid in the tube.

b. Carry the ap. (holding it by the tube so that the air in the bulbs will not be affected by the heat of the hands) to a cold place (*e.g.* into a cellar refrigerator, near a cake of ice, etc.). Note and explain phenomena.

204.

Ap.: porte lumiere, tank, lens; chemical thermometer, having its bulb covered with lampblack soot; ring-stand and clamp holding a card; bottle holding an almost opaque solution of iodine in disulphide of carbon, and another containing a concentrated solution of alum in water.

Sifting ether waves. *a.* Throw a beam of light through the lens and bring it to a focus on the card. Fill the tank with alum solution and place it in the slide-holder of the lumiere. Replace the card by the bulb of the thermometer, so that it will be in the focussed light. Note the change of temperature in five minutes.

b. Pour the alum solution back into the bottle, rinse, and wipe the tank dry; fill it with iodine solution and repeat *a.*

c. Which of the solutions is more transparent?

d. More diathermanous?

e. Which transmits long waves readily, but is nearly opaque to short waves?

f. Which transmits short waves readily, but is quite opaque to long waves?

205.

Ap.: two 2 oz. flasks, one covered with tin-foil on the outside, the other covered with lampblack (from a candle flame); two chemical thermometers; and hot water.

Radiators and radiation. *a.* Both flasks are filled (by the teacher) with hot water at the same temperature. A thermometer bulb is suspended in each. The pupil will make observations of the temperature of each at equal intervals of ten minutes for half an hour.

Which surface shows the greater ability to radiate heat?

b. Tabulate results of your observations.

c. Is the rate of cooling greater or less when the difference between the temperature of the hot body and the surrounding space is greater?

d. When the mercury in a thermometer has nearly reached the temperature of the gas or liquid into which it is plunged, are its changes rapid or slow?

e. What precaution does this suggest in testing temperature with a thermometer?

206.

Ap.: porte lumiere.

Convection. *a.* Project a circle of light on a white screen. Let a person stand in the path of the light, a few feet away from the screen, so as to project a shadow of his head and of an extended hand upon the screen. Something that seems like smoke appears on the screen to ascend from the head and finger-tips. Explain the phenomenon.

b. What method of heat diffusion does this illustrate?

CATALOGUE OF APPARATUS.

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